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# ADVENTURES IN SCIENCE

*Edited by*

B. C. BROOKES, M.A.

WILLIAM HEINEMANN LTD
MELBOURNE :: LONDON :: TORONTO

*First published 1951*

*Printed and bound in Great Britain by*
*William Clowes and Sons, Limited, London and Beccles*

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Puzzles, Problems, and other short items of interest will be found as tailpieces to the main features.

# About this Book

THE aim of this book is to show you that science is an exciting subject, though of course not in the way that a football match is exciting. The study of science is an adventure into the world of ideas, and that is why we have called the book *Adventures in Science.* We hope that after reading it you will try to do something in a practical scientific way: for example, to make a telescope and observe the stars, or to make a formicarium and observe the life of ants. We hope also that the modern developments of science described in this book will stir your imagination. If, after reading this book, you become a little more observant of nature, a little more critical of newspaper reports of scientific discoveries, a little more amazed at the vastness of the universe and at the complexity of living things, then we (and you) ought to be satisfied.

If you are attracted to science because you would like to discover new facts about the world we live in, you can become a research scientist. If you are interested in making practical use of scientific discoveries for the benefit of mankind you can become an engineer or an applied scientist. Even if you have already decided to follow a career outside science it is important that you should understand how scientists think about their work. The two articles on *Careers in Science* may help you to decide your future.

Science is such a vast subject that one book can describe only a very small fraction of its wonder and its applications. Do not be disappointed therefore if this book does not answer all your questions about science. If there is something you would like to read about and which we have not included this time, write to the Editor, *Adventures in Science*, c/o Messrs. Heinemann, 99 Great Russell Street, London, W.C.1. Tell him what it is you want and he will do his best to please you next time.

B. C. BROOKES

Contributions to future issues of *Adventures in Science* are invited. Details of requirements can be obtained from the Editor, *Adventures in Science*, c/o Messrs. Heinemann, 99 Great Russell Street, London, W.C.1.

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# Looking at the Stars

### ALAN HART

THE first step is to see if you have available a small telescope or a pair of field-glasses. If you have one of these, or if you can obtain the use of one, that is good enough. Telescopes and field-glasses, by the way, consist of a "long-focus" or weak magnifying lens at the front end with a "short-focus" or strong magnifying lens as the eye-piece. In the case of an opera-glass, the eye-piece is a short-focus concave or reducing lens. If you have a pair of opera-glasses, they will be too weak to be of much help as they stand. If, however, you can get a long-focus lens to go with one of the eye-pieces from the opera-glass, this may give a pair of lenses which can be combined to give an instrument more suitable for our purpose.

If you have no optical instruments at all, then you can try to obtain two magnifying lenses of different strengths in order to make a telescope yourself. The greater the difference in the strengths of the lenses, the greater will be the magnification of the resulting telescope. First find the approximate distance apart of the lenses which enables you to see clearly a distant object through them. Then make two cardboard tubes which slide one in the other to give this distance, and mount the two lenses at each end. If you use two magnifying lenses in this way, things will appear upside-down through the telescope, but this does not matter for looking at the night sky. If you have used the concave lens from a pair of opera-glasses as eye-piece, things will appear right way up.

In order to know what you may reasonably expect to see with your instrument, you need to know its magnification and the diameter of the objective (that is the front or weaker lens). The first of these is found by looking at a brick wall through the telescope keeping the unused eye open. In this way, you see the magnified wall and the unmagnified wall together and can count how many bricks a magnified brick covers.

If you are using a telescope you should make some sort of support for it from wood or meccano; if a support is not forthcoming, or if you are using field-glasses, rest the instrument against a wall or post when you are observing, as it is important to keep the instrument still to get good results.

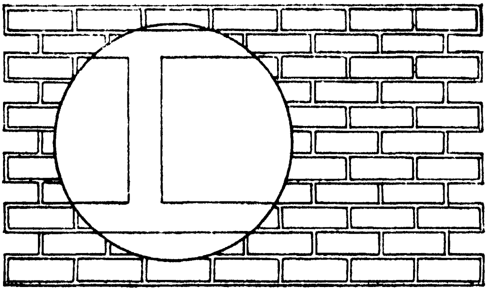


Fig. 1. This telescope has a magnification of 6.

We can start by looking at the Moon. To see some of the craters on the Moon you need a telescope magnifying about twelve times. This should also show the craters called Plato and Copernicus. To begin to see any mountains you need a magnification of about thirty. It is best, in observing any particular feature, to choose a night so that the feature is only just illuminated, with the eye of the shadow near it, rather than to try to see it at full moon, so that the mountain or crater has a long and comparatively easily seen shadow. Of course, if you have a magnification less than those mentioned, you will see the "plains" and "seas" more clearly even if you cannot see any craters.

There is no completely satisfactory explanation of the existence of the craters. One theory supposes the moon to have been hit by many meteors, which threw up material to form the craters we see. However, if this is so, it is only reasonable to suppose that the Earth would also have been so bombarded, yet no traces (except for a small crater in Arizona) of any such bombardment can be found, not only on the surface, where wind and water might well have removed them, but also in the underlying rocks. A rival theory supposes that the craters are extinct volcanoes, but they do not look like the volcanoes on the Earth at all; and they are so very large, up to a hundred miles in diameter. There are other unsatisfactory theories as well. The white streaks which you may be able to see radiating from Copernicus, and elsewhere, are probably deposits of dust. The Moon is, of

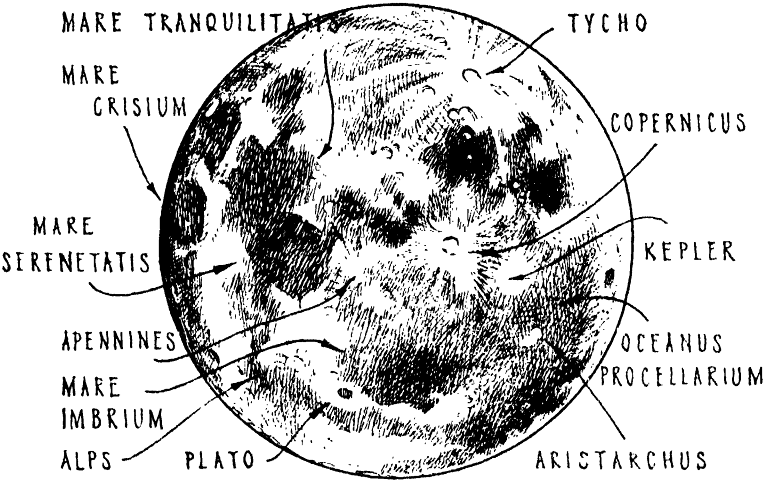


Fig. 2. Sketch-map of the Moon.

course, a dead world; there is no water, there is no air there, and we could see anything the size of a city block or a wood.

Leaving the Moon, we turn to the planets. First you will want to know how to find them. There are few planets which you will be able to see, and only if they are in suitable positions: Venus, Mars, Jupiter, and Saturn. Mercury and Uranus are very difficult to find, as Mercury is always very close to the Sun, and Uranus can only just be seen as a faint star. The planets will always be found near the plane of the ecliptic, marked on the chart.

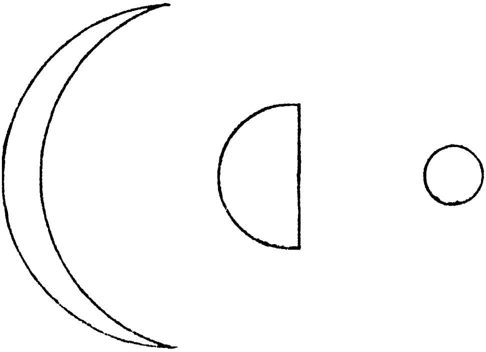


Fig. 3. The Phases of Venus.

Taking Venus first, it is always to be found fairly near the Sun, as its orbit is inside that of the Earth. This means that you can see it only low down in the western sky just after sunset (or in the east before dawn—but this may not appeal to you). It is easily identified, as it is much brighter than any of the stars and does not twinkle. This absence of twinkling is a very good way of telling a planet from a star. Venus shows phases, like those of the Moon, when seen through a telescope, and you should be able to make out the crescent phase with a magnification of about twenty. The best time to look at Venus is in bright twilight, as soon as you can pick it out. Opposite is a diagram of the phases—can you decide why the crescent phase is the largest?

Not very much is known about Venus, as it is covered by clouds, probably of dust, floating in a carbon dioxide atmosphere. There is very little, if any, water or oxygen on Venus.

Jupiter is also quite an easy planet to spot. It appears as a very bright star, shining with a steady, rather yellowish light, so that if you see an object of this description and you cannot find a star in its position on the chart, it is Jupiter (but do not confuse it with Saturn). Jupiter has four large moons, and you may just see them with an aperture of one inch and a magnification of ten on a very clear night. They appear as four little stars (thought not all may be visible at the same time) near Jupiter, all in the same straight line. If you watch from night to night, you will see them change their positions relative to Jupiter as they describe their orbits around the planet. Jupiter also shows a disc, that is, it is not a point of light like a star, but greater power is needed to see the disc properly than to see the moons. With a good two-inch-aperture telescope Jupiter is seen to be a flattened disc with horizontal belts or shadings. It is a very large planet with an atmosphere of ammonia and methane. It has a surface temperature of about $-150°$ C.

The other two easily observed planets are not very good objects for small telescopes.

Saturn has the well-known ring system, but a two-inch telescope with a magnification of about fifty is needed to see them, and with a very small telescope you will probably not even see the planet as a disc. Saturn is rather more difficult to identify than the others we have discussed; it appears as a bright star shining with a steady light. The physical conditions on Saturn are much the same as on Jupiter. It is thought that the rings are fragments of a satellite of Saturn which has been broken up by the planet's gravitational attraction.

Mars, which has caused such controversy, is very disappointing to see. It is a moderately bright star shining with a steady reddish light. It is therefore easy to spot (if it is on view), as only two or three other bright stars are reddish, and, as we have said, it does not twinkle and it is of course not on the star chart. All that can be seen of Mars with quite a good telescope is a disc. The general opinion about Mars is that plant life probably exists there, as shown by seasonal changes in colour on the surface of the planet. It is very unlikely but not impossible that higher animal life could exist there. For one thing, there is hardly any oxygen in the atmosphere, and very little water. Also, the daily variation in temperature on the planet is about 100° C., yet the equator at noon has a temperature of only 10° C.

We will now leave the solar system for the present and have a look outside it. The first class of objects to notice are double stars. It is found, with the use of powerful telescopes, that very many stars are not single as they appear to the eye alone, but are really two or more stars close together. It is also found, indirectly, that many stars which look single even in the biggest telescopes are in fact doubles. This fact that many stars go about in pairs suggests that there is a physical connection between the members of the pair, and this is the case. Each star is attracted to the other by gravitation, just as Newton's apple was attracted to the Earth, and they each go round a point between them, in ellipses. Most of the stars of this class cannot be seen as doubles with the small instruments at our disposal, but there are a few which can be tried. A very easy one is θ Tauri (see the chart); the two components can almost be separated by the eye alone. Another easy one for small telescopes is ε Lyrae; actually each of the component stars is double, but you will not see this. Other double stars are more difficult, but here is a short list in case you have the use of a good telescope: ζ Ursae Majoris, β Cygni, β Lyrae, and *Cor* Caroli.

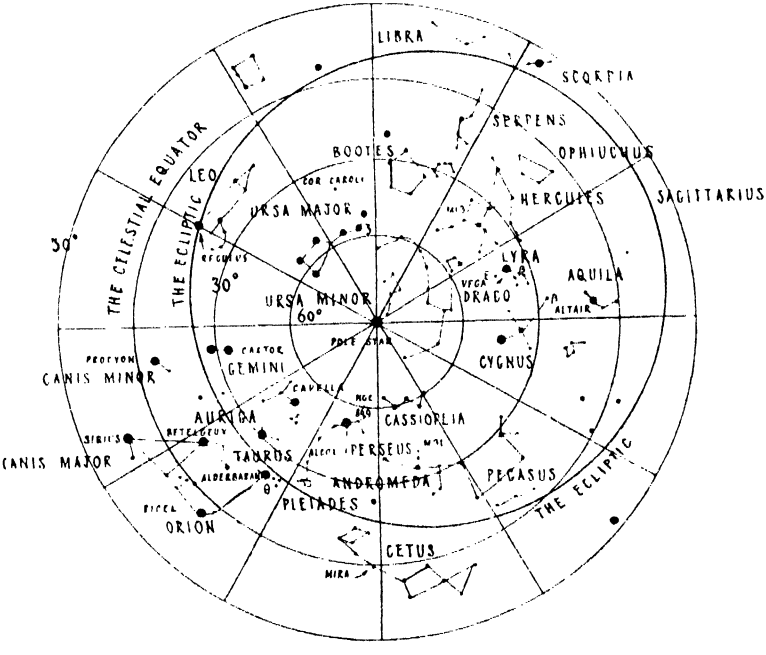


Fig. 4. Star Chart.

A word about the system of naming stars may be of use here. The stars are divided into groups or constellations, and a letter of the Greek alphabet is allotted to each star in the constellation in order. The name of the star therefore consists of the Greek letter together with the genitive case of the Latin word for the constellation, e.g. ζ Ursae Majoris is the sixth star in the Great Bear. Some bright stars have special names also; for example α Canis Majoris is always called Sirius.

Some of the stars in our galaxy are together in clusters, and there are two of these which are worth looking at. Near the easily recognized constellation of Leo there is a small hazy patch of sky. On looking through a small telescope at this patch you will see a cluster of faint stars; the name of this cluster is Praesepe (the Beehive). The Pleiades are also easily found and are well worth looking at through the telescope; instead of about six stars seen by the eye alone, we can see many more. Two small and faint clusters are M 13 in Hercules and NGC 869, near Cassiopeia, but these are difficult to see well with a small telescope.

Now we turn to the nebulae. These are masses of gas either inside or outside our universe. Below the three stars forming the "belt" of Orion, there are two less bright stars at right angles to them, and by the lower of these is the nebula in Orion. This is just visible to the eye, and is a fine object in a good telescope. Above the middle star of the three bright stars of Andromeda are two fainter ones, and just above these is the Great Nebula in Andromeda, which is another universe like our own, five million million million miles away. You will see it as a small bright patch; it is also just visible to the naked eye.

Lastly you can try observing the Sun. Do NOT do this by looking at it through a telescope, as it might cause permanent local blindness in your eye. Instead, mount the telescope pointing at the sun, and place a piece of white card about nine inches from the eyepiece. Adjust the focus of the telescope until you obtain a sharp image of the Sun on the card. Now look to see if there are any dark specks on the image. If there are, and if their position on the Sun's disc is unaltered by moving the telescope, the specks are sunspots. If you cannot find any the first time, try at a later date, when the Sun has had time to turn on its axis (it takes 25 days per revolution) so that the other side is visible. The sunspots are gigantic vortices on the Sun's gaseous surface, and, as you may be able to see for yourself, they very often appear in groups.

It will be interesting now to conclude with a sketch of the way in which the Earth and the other planets came into being. As you may perhaps know, it used to be thought that the planets were "pulled off" the Sun by another star which happened to come near. This theory falls down when we consider that the Earth is largely made of heavy elements such as iron, silicon, aluminium, and oxygen, whereas the latest work shows the Sun to be 95 per cent hydrogen.

It is now thought that the Sun was originally one component of a double star. The other component was much more massive than the Sun, so that it radiated away heat rapidly into space. It did not, however, get any cooler, and the loss of energy was made up by the conversion of hydrogen to helium within the star. Eventually, when the hydrogen became used up, the star began to contract, but in contracting the star became hotter and hotter until it reached a temperature at which nuclear reactions occurred and produced the heavy elements. The reactions used a tremendous amount of energy which was provided by the continued rapid collapse of the star. But as the star collapsed, and in conformity with what is known as the "principle of the conservation of angular momentum", it spun round ever faster and faster until the centrifugal forces were great enough to fling the star in all directions in a colossal explosion. A star which explodes like this is called a "supernova". It is thought that a small part of the exploding star was attracted to the Sun and spun round it; from this mass of gas the Earth and the other planets condensed. Supernovae are occasionally to be seen in the sky; have your telescope ready in case you can follow the progress of the next one that is reported!

## A BANANA PROBLEM

Four men spent a day picking bananas and were so tired at night that they went to sleep without dividing the bananas. One awoke during the night and decided to take his share. He divided the pile into four equal parts, but found that there was one banana over, which he threw to the monkeys who were watching. He hid his share, heaped the rest together, and then went to sleep again. A second awoke and did the same; he took a quarter of the heap he saw, and again threw the odd banana to the monkeys. The other two awoke in turn and did the same. In the morning they all decided to say nothing of having taken their shares and so the remaining pile was again divided into four; again there was one over for the monkeys.

What is the smallest number of bananas they could have collected the day before? (Answer on page 64.)

# Radar Pictures

R. H. CAMPBELL

I SUPPOSE most people nowadays know that radar can "see" objects in the dark, through fogs and cloud, and at distances too far for human eyes to see. Also they know that it works by detecting an echo that is reflected back to the radar set from ships, aircraft, or other "targets" that come into the path of the radar beam. But what is it that the radar operator sees or hears?

It is about what the operator sees that I am going to write, because in very nearly all radar sets the operator watches for his targets on the screen of a cathode-ray tube, the same kind of tube which is used in television receivers. We say "target" although the object located may not be an enemy; it may be a landmark, such as a coastline, mountain, or city.

As a beginning to our discussion of what the radar operator sees, let us think what an operator needs to find out to know exactly where a target is. Suppose the operator in ship A detects ship B coming towards him. To know exactly where B is he must find out two things:

(*a*) The distance AB between the two ships.

(*b*) The angle, measured clockwise, between the direction ship A is moving in, and the line AB. Thus the angle of 45° indicates that B is on the starboard bow.

These two pieces of information are called the *range* *and bearing of the ship B. Notice that this information* gives the position of ship *B* as it would be on a chart. If the radar is fixed in a position on land, then the bearing angle is usually measured from the north. These two quantities, range and bearing, are measured by any radar that gives its information in the form of a map—the most convenient way of seeing the situation at a glance. How can we measure these quantities by using a radio echo? The radio waves travel with the speed of light, 186,000 miles per second (in fact, light and radio waves are both electro-magnetic waves, different only in their wavelength). This high velocity means that it takes only 100 microseconds for the echo to travel 10 miles and back (a microsecond is one millionth of a second, and is the usual unit used in measuring these short time intervals). A time interval as small as this between the sending and the receiving of the radio wave is far too short for any human or mechanical method of measurement, so it must be done electrically with an indicator that has no inertia—nothing massive about it that will cause it to lag behind in the very quick movements it must make to record 100 microseconds accurately. We have the very thing in television's Cathode Ray Tube, shown displayed in Fig. 1.

A cathode ray is a beam of electrons and therefore it has practically no inertia, since electrons are the very small light negative-charged particles that form all the outer part of an atom that is not inside the heavy positive nucleus. The electrons are called cathode rays when they are used in the tube because they start on the heated cathode, or negative end of the tube, and because, when they were first discovered, people were not sure whether they were rays or small particles. After leaving the hot cathode the negative electrons are attracted up the tube by the positive electron gun. They move at very high speed, and as they go they form into a very fine beam that produces a small spot as it hits the "phosphor" with which the flat face of the tube is coated, and which emits visible light when hit by high-speed electrons. The picture is produced by voltages between the plates marked X and Y in Fig. 1. The voltage between the X-plates will attract the electron beam in the left-and-right directions, while the Y-plates cause the beam to move in the up-and-down directions.

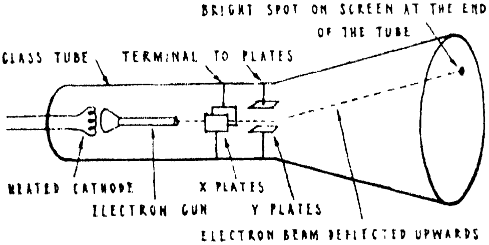

BRIGHT SPOT ON SCREEN AT THE END OF THE TUBE
GLASS TUBE
TERMINAL TO PLATES
HEATED CATHODE
ELECTRON GUN
X PLATES
Y PLATES
ELECTRON BEAM DEFLECTED UPWARDS

Fig. 1. A cathode-ray tube.

We can therefore make the spot on the face of the tube move to any part of the screen, and thus make it draw a picture by putting suitable voltages on the X- and Y-plates, as is done in a television set. Some cathode-ray tubes use the magnetic fields of coils instead of charged X- and Y-plates to deflect the spot; in this case the spot is moved about by varying the coil current. The electron beam can be moved across the screen as quickly as we please, in times as short as one microsecond if necessary, so that the length of line drawn by the spot will be a suitable indicator of the short echo times of radar signals. I shall describe later some of the sets actually used to measure the echo times.

If the cathode-ray tube will measure the echo time, what about the bearing angle of the target? The aerial itself will measure that! Perhaps you did not realize that an ordinary piece of straight wire receives and transmits better in one direction than another, though many of you will know that a loop of wire receives best when the plane of the loop is in the direction of the signal. The straight wire receives best when it is broadside on, and is more efficient at both sending and receiving when it is half a wavelength long. (A wavelength is the distance between two successive crests.) This fact about aerial length leads us to use the short waves for radar, since half a wavelength in the medium waveband (London Home Service is 342 metres wavelength) would be very awkward for pointing at targets. The use of short waves is made more obvious by the fact that an "array" of aerials spaced a quarter of a wavelength apart, one above the other or side by side, much increases the directional effect.

Let us see how these ideas are used in practice. The first radar stations in the world, still in some respects (notably that of range) the best, were the British CH (Chain Home) stations, built just before the war. These sets won the Battle of Britain for us in 1940, by making it no longer necessary for us to waste our few fighters in standing patrols; we could send them up only when our radar told us a raid was on the way.

There were two aerial arrays in a CH station, arranged as in Fig. 2, one receiving from Area 1, and the other from Area 2. An aircraft in Area 1 gives a bigger signal to aerial 1 than to aerial 2, and vice versa. An aircraft on the dotted line as shown gives equal signals to both aerials. Thus a comparison of the signal strengths from each aerial gives the bearing angle of the target aircraft. The wavelength used was about 30 metres, no shorter since at that time enough power could not be obtained from the transmitter valves at any shorter wavelength to get sufficient echo back to the receiver. The range was measured by causing the transmitter to send a signal in the form of a short "pulse", lasting only a few microseconds, after which the transmitter closed down, while the receiver listened for echoes. This method of transmitting is necessary for the receiver to be able to tell echoes apart. Continuous transmission would mean that near and far echoes would arrive all mixed up. After a pause to wait for all wanted echoes to arrive back, the transmitter sends another pulse. At the same time that the transmitter sends its pulse, the cathode-ray tube is made to start its spot moving across the screen from left to right, drawing a line right across the screen until after the furthest possible echo could have got back

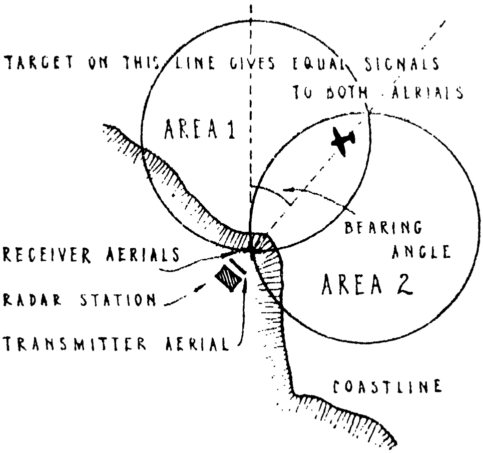


Fig. 2. The aerial arrangement of a CH station.

to the receiver. Then the spot is switched back to the left-hand side to await the next transmission pulse. When an echo gets back to the receiver it is used to cause a sudden kick in the voltage on the Y-plates, deflecting the beam upwards. Thus at the time of the arrival of the echo there will appear a sudden "blip" on the trace or scan, as in Fig. 3. The distance of the blip from the left-hand side of the trace is a measure of the distance of the echoing target, since the trace or "time-base" records the time of flight of the radio pulse. Short radio waves travel in straight lines, so that for radar the horizon is the limit, but this is not such a drastic limitation when we remember that an aircraft at 20,000 feet is still over the horizon at 150 miles, and this range is what can be achieved with a CH radar. This simple presentation is a long way from the navigator's dream of having range and bearing presented to him on a map, but it is simple and still remains one of the most accurate means of long-range detection.

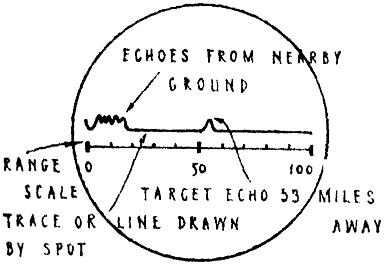

ECHOES FROM NEARBY GROUND
RANGE SCALE
0
50
100
TARGET ECHO 53 MILES AWAY
TRACE OR LINE DRAWN BY SPOT

Fig. 3. The face of a CH tube.

Radar became airborne at the beginning of the war, when the use of shorter wavelengths (about one metre) made aerial arrays much handier so that they could be mounted on each wing, one pointing to port and the other to starboard. A further saving in space and weight was obtained by using the same aerial for both sending and receiving. The set was called ASV (Air-to-Surface-Vessel), and although not suitable for use against ground targets it was used with great success by the Fleet Air Arm and Coastal Command in hunting for enemy convoys and surfaced submarines (note that radar cannot find a submarine unless at least a periscope is showing above water, as radio waves cannot penetrate the sea surface). In the picture on the screen (Fig. 4) the time-base goes vertically up the screen, while echoes go to the left, and those from the starboard aerial to the right. In the drawing the target ship is to port since the port echo is bigger. The aircraft would now turn slowly to port until the echoes are equal, and then it would be flying straight towards the target. There are few echoes from the sea to confuse the picture except from just below the aircraft, so that the first echo will give the height of the aircraft above the sea.

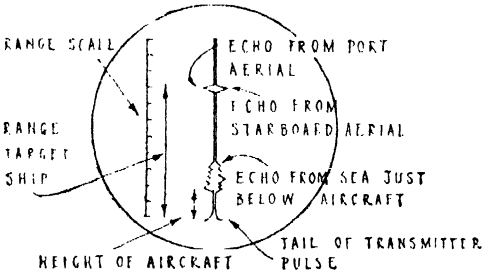

RANGE SCALE
ECHO FROM PORT AERIAL
ECHO FROM STARBOARD AERIAL
RANGE TARGET SHIP
ECHO FROM SEA JUST BELOW AIRCRAFT
TAIL OF TRANSMITTER PULSE
HEIGHT OF AIRCRAFT

Fig. 4. The scheme of ASV radar.

The fact that while objects on the ground echoed well the sea hardly echoed at all, led designers to think that perhaps the ideal map-like picture could be achieved, with the sea dark (no echoes) and the land light. This could be done only if the aerial sent and received along a narrow beam, while the echoes were recorded in their proper place in the right direction on the tube screen. To get really narrow beams, it is necessary to use "microwaves", whose wavelength is about 10 centimetres or less, or the aerial would be far too large. But the big snag in using these centimetre waves is that the connecting wires are themselves about the size of a wavelength, and this stops us using ordinary radio gear. The British scientist Professor Randall solved the difficulty during the war when he invented the "cavity magnetron", by putting all the radio circuits *inside* the oscillator valve. From 1942 onwards nearly all radar used these high-power magnetrons as in Fig. 5. Radio waves travel from the magnetron to the aerial, and the echoes go back to the receiver along hollow pipes or "waveguides" which have to be used instead of connecting wires. At centimetre wavelengths the radio waves are very much like light; they can be focused into a beam by a parabolic reflector as in a torch or headlamp, and this can be turned round to point in any desired direction. The picture on the cathode-ray tube in this microwave ASV was a great improvement, and is shown in Fig. 6.

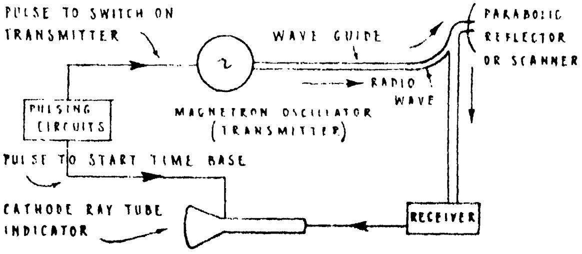

PULSE TO SWITCH ON TRANSMITTER
WAVE GUIDE
PARABOLIC REFLECTOR OR SCANNER
RADIO WAVE
PULSING CIRCUITS
MAGNETRON OSCILLATOR (TRANSMITTER)
PULSE TO START TIME BASE
CATHODE RAY TUBE INDICATOR
RECEIVER

Fig. 5. Typical radar circuit.

As the transmitted pulse leaves the aerial going outward, the spot of light starts from the centre of the tube face, and moves out to the edge in the same direction as the aerial is pointing. The time-base is normally darkened but the echo is used to light it up. As the aerial turns round the time-base moves round with it, like a clock hand, painting an echo map of the area scanned by the aerial. This map will be to scale, since the distance along the trace is a measure of target range as in earlier sets. The map stays on the tube face, since the phosphor is of a kind that glows for some time after the electron beam has hit it. The map may not be perfect, especially at the edges where the echo is weak, and behind hills that may blanket the land beyond, but the two essentials of range and bearing are given immediately. Sets using this type of PPI or "Plan-Position-Indicator" in our ships and aircraft won the Battle of the Atlantic for us in 1943. It was soon discovered that towns, roads, and railway lines gave better echoes than open country, while rivers remained dark, so that the set could be used entirely over land with good pictures at ranges up to 30 or 50 miles. In the form called "H2S"

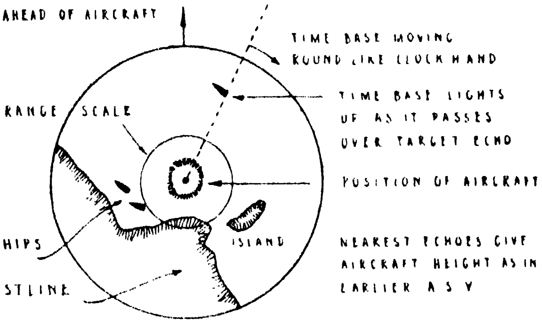

AHEAD OF AIRCRAFT
TIME BASE MOVING ROUND LIKE CLOCK HAND
RANGE SCALE
TIME BASE LIGHTS UP AS IT PASSES OVER TARGET ECHO
POSITION OF AIRCRAFT
2 SHIPS
ISLAND
NEAREST ECHOES GIVE AIRCRAFT HEIGHT AS IN EARLIER A S V
COASTLINE

Fig. 6. Microwave ASV picture.

these sets were widely used for blind bombing by Bomber Command and the U.S.A.A.F.

We have been considering map-like pictures of the surface of the Earth. Suppose we want to bring in the third dimension to find the height of a target aircraft. In Fig. 7 it is shown how radar finds this indirectly by measuring the elevation angle between the ground and the line joining radar to target, as well as the range. A little trigonometry then gives the target height. In the earliest CH stations the elevation angle was measured in the same way as the bearing angle by comparing the signals received by two further sets of aerials pointing upwards at different angles. This is the simplest method of height-finding, but it does not give you the situation at a glance. Before the use of microwaves, the AI (Aircraft Interception) sets used in night fighters were similar to the earlier ASV sets, but with two sets of aerials pointing ahead, and with two tubes, since it is impossible to represent three dimensions properly on a flat tube. The target aircraft was as before in the direction of the biggest echo on each tube, and always had to be ahead of the fighter, so that fighters had to be directed by a ground station to a position just behind the target. The aircraft's own radar then took over.

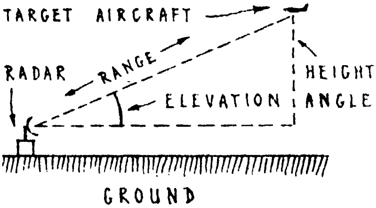


Fig. 7. Height-finding by radar.

One attempt to put all three dimensions on one tube was made with microwave AI sets built in 1941–42. They did not use a very narrow beam, so that some signals could still be received even if the scanner was not pointing full at the target. It started pointing dead ahead and then moved outward in a spiral. As it did so, the time-base, like a clock hand as with the PPI, moved round with it (see Fig. 8) and lit up only in the correct range position as the set received an echo. If the target aircraft was dead ahead of the fighter, then the fairly broad beam aerial would detect echoes all the way round the spiral, the result being a ring picture. If now the target is to one side, echoes will only be detected from that side since the aerial beam is not that wide. If the pilot wants to attack aircraft B in Fig. 8, he climbs and turns to starboard till the arc echo turns into a circle. Then he flies straight on, overhauling the target as the circle gets smaller and smaller, until finally, as the circle disappears into the spot at the tube centre, the fighter is just behind the target, and in a position to fire at it.

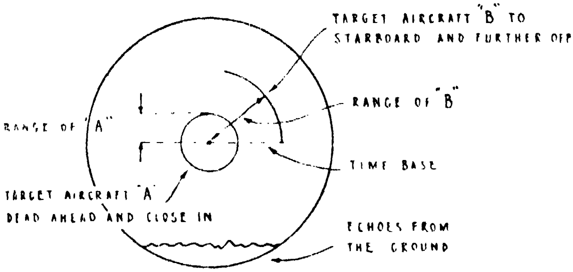

TARGET AIRCRAFT "B" TO STARBOARD AND FURTHER OFF
RANGE OF "B"
RANGE OF "A"
TIME BASE
TARGET AIRCRAFT "A" DEAD AHEAD AND CLOSE IN
ECHOES FROM THE GROUND

Fig. 8. Microwave AI indicator.

With the development of microwaves the use of indicators giving the situation at a glance became common in ground radars used for locating enemy aircraft. Two tubes were used, one a normal map-like PPI giving range and bearing, the other giving accurately the range and height of the same target echoes that were lighting up the PPI trace. This needed two aerials, one giving a narrow beam sideways, for finding the bearing angle, and the other one giving a narrow beam vertically for height-finding. The two aerials were rotating on the same mounting, so that they were both receiving echoes from the same targets.

Perhaps one of the most accurate radars in frequent use was an American ground-based radar, SCR 584, used for anti-aircraft gun control. There was only one aerial, which produced a very narrow beam like a torch beam so that it could measure both bearing and elevation. The aerial turned itself continually in all directions until it located a target. There were three tubes, one a PPI giving all possible targets on a map. The other two were for measuring range, while elevation was measured by a dial worked by the direction of the aerial itself. One of the two range tubes is shown in Fig. 9.

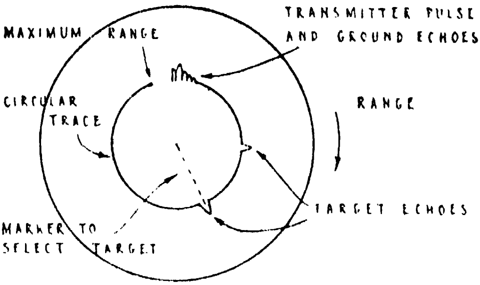
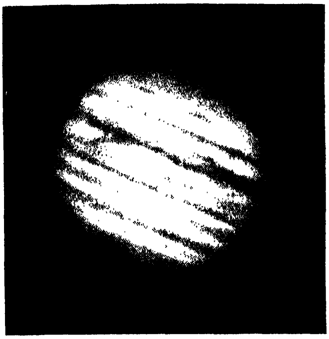


Fig. 9. Coarse-range tube, SCR 584.

The trace is circular, starting at the top and working round clockwise. The coarse range tube gives the range to the nearest 1000 yards, while the fine range tube

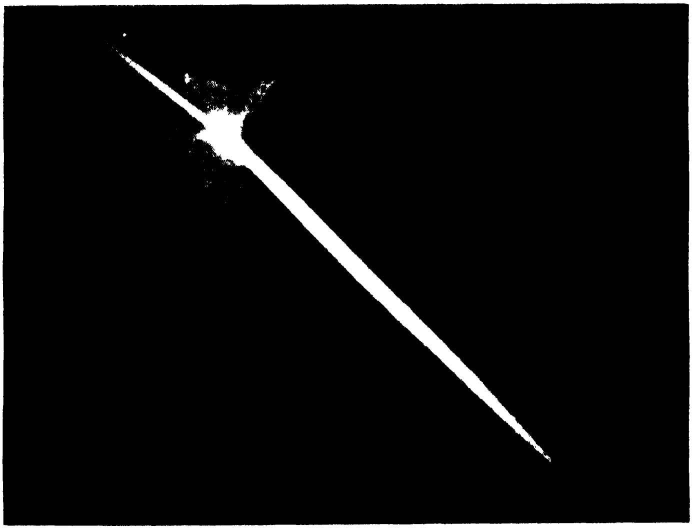
# PLATE I. LOOKING AT THE STARS



Jupiter

Saturn

*(Both by courtesy of Lick Observatory)*

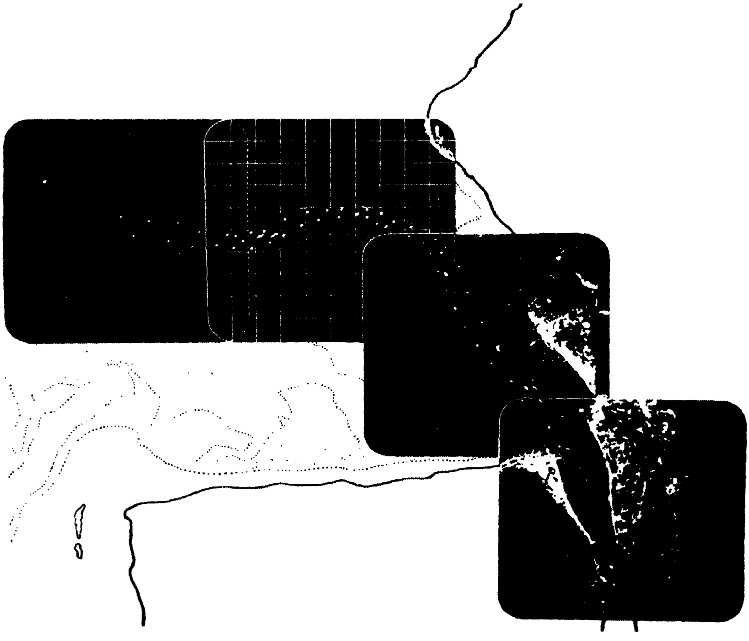


Exploding Meteor

*(By courtesy of C. P. Butler)*

# PLATE II. RADAR PICTURES

Detail of screen pictures



Ships approaching Liverpool viewed by radar

(*Both by courtesy of Sperry Gyroscope Co. Ltd.*)

shows, on a larger scale, the part round the target selected by the marker. By this method the range can be measured to about 25 yards. The aerial beam is kept directed automatically on to the target which has been selected by the range marker, without any further control by the operator. This is done by wobbling the aerial slightly, and noting in which direction of wobble the maximum signal occurs. This signal is then used to drive the aerial-scanning motor in the same direction. In the British version of this set, the guns are similarly pointed at the target by the auto-tracking aerial (after a suitable correction for the time-of-flight of the shell has been added).

There are many different kinds of pictures used in radar, and so to end I can only just mention a few interesting ways of giving radar information. There is the GCA system (Ground-Controlled Approach) in which the pilot of an aircraft can be "talked down" to a perfect landing, if he gives up control of the aircraft to the landing officer on the ground. The indicator for this is a spot to be kept dead central on the screen. There is a similar indicator used in some AI sets for night fighters in which the spot grows "wings" as the fighter approaches its target—so looking more like a "picture". When the wings are big enough, the pilot knows he is within firing range. Then there are ship gunnery-control radars that are so accurate that near misses can be distinguished from hits by the additional echo that appears on the range tube due to the splash made by the near miss on the water. Some radars have been arranged only to show echoes from moving targets, so that they are especially useful for tracking aircraft in places where there are also strong echoes from the ground. Finally, there is the IFF set (Indicates Friend or Foe) carried by all friendly aircraft. This gives a much bigger echo than usual back to the interrogating radar—a coded echo that tells the ground station that the aircraft is friendly. Any aircraft that gives only the normal echo must be regarded as hostile unless identified by sight.

## CAN YOU PLAY NIM?

Nim is a simple Chinese game that can be played with matches (or stones or beans—anything convenient). The matches are divided into several heaps—as many as you like—but three is the minimum. There are two players, who take it in turn to begin play. The first player is allowed to take matches from any *one* of the heaps; he must take at least one, and he can take the whole heap if he likes. Then the second player takes as many matches as he wishes from any *one* of the heaps. The game is played in turn in this way until one of the players has to take the last match; he is the loser.

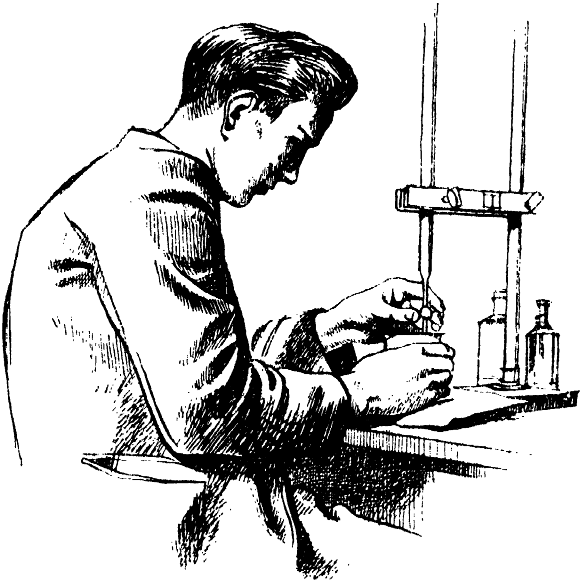
This simple game has interested famous mathematicians and the theory of it has been completely worked out. It is almost always possible to win at Nim—if you know how! For example, if you can arrange to leave for your opponent two heaps with two matches in each heap, you are bound to win. If your opponent takes the two matches in one of the heaps, you take one match from the other. If he takes one match from one heap, you take both matches from the other heap. Another end position to work for is to make three heaps, with one, two, and three matches, but in this case you must be careful, as you can discover for yourself by experiment.

*CAREERS IN SCIENCE I*

# The Research Chemist— What He Does and How You Become One

J. CHATT, M.A., Ph.D., F.R.I.C.

RESEARCH is a magic word, conjuring up pictures of great discoveries in all branches of knowledge, but particularly in Natural Science. This is the knowledge of the forces which control the behaviour of material things, which vary in weight from electrons to galaxies



The young laboratory assistant.

and in complexity from neutrons to living matter—ourselves. These discoveries were not luck, but the results of intense curiosity, a keen sense of observation, and the persistent efforts of many individuals, the few great men whose names will be known to endless generations of schoolboys, and the countless "backroom boys" of the University, Industry, and Scientific Civil Service, of whom research chemists are no mean proportion.

You will be familiar with elementary science and there is no need to tell you what chemistry is, or that a chemist practises the science and art—for it is an art—of chemistry. It is a freak of our language that the pharmacist, who mixes and sells medicines but needs only an elementary knowledge of chemistry, is also known in Great Britain as a chemist. He does not practise chemistry, although he mixes and sells some of the products of chemical industry, so his profession does not concern this article. We are interested in the man who obtains pure chemicals from their ores or other natural sources, converts them into other useful substances—for example, limestone and common salt into washing soda—studies how these changes occur, controls them, and separates the new substances or products from one another.

Let us consider in more detail what the research chemist does. Chemical research is conveniently divided into two types—fundamental and applied. Fundamental research is the investigation of pure chemistry for its own sake, finding out the laws of chemistry, the ways in which the different atoms combine, how and why chemical reactions occur. This may sound very difficult when stated in this all-embracing manner, but anyone, provided he is sufficiently interested to study and master a branch of chemistry, can see unsolved problems to which solutions may be found by devising and carrying out suitable experiments.

Applied chemical research is the investigation of the ways in which the existing knowledge of pure chemistry can be applied to practical problems, to provide materials of use to the community. It is the province of Chemical Industry, and employs the greatest number of research chemists. The problem to be solved is set by the needs of the community as interpreted by those directing the industry, and presented to the research chemist or team of chemists.

Fundamental research is essentially the work of an individual, although he may have many helpers. It is largely carried out by university teachers, in university laboratories, with the help of their postgraduate students. The successful professor may have as many as twenty students working with him at one time, but up to six is a more usual number. Applied research was once the job of "inventors", again individuals, who by devising something of use to the community were able to sell it and thus make a living. Now it is usually carried out by teams of workers with different standards of attainments and interests in the employ of Chemical Industry, or the Ministry of Supply. Applied research involves much work of a routine or semi-routine character, and the less able research chemists, or chemists in training, often find themselves doing such work in these research teams.

There is no hard and fast dividing line between fundamental and applied chemistry. Fundamental work is often done in industry when the need for fundamental information not already available arises.

Conversely, some work, capable of immediate application, may be carried out in the university.

Perhaps I should now tell you how chemical knowledge is recorded. Suppose you are an individual research chemist and you are particularly interested in compounds having an organic radical attached to an alkali metal. Let us also suppose that such compounds are unknown. You first try to make one, perhaps methyl sodium, $CH_3Na$. If you have sufficient knowledge of chemistry and experimental skill, you finally succeed in this rather difficult task (methyl sodium explodes on exposure to air). Engaged in this sort of pursuit you are certain to be a member of some national chemical society, so you now write an account of your work, known as a paper, and present it to the society for publication in their journal so that other chemists can read how you prepared this dangerous substance and what its properties are.

There are hundreds of journals in many languages which publish the results of both fundamental and applied research. In addition, much applied research is patented and published in the form of patents. It is impossible for anyone to read all the journals and patents. The Journal of the Chemical Society (London), which is quarto size, appears every month; it is, at present, about one inch thick and printed in rather small type, but this is only one—although one of the larger journals—so you can guess what an enormous quantity of new work appears each year.

Because you cannot read all these journals even if you could read all the languages, summaries known as "abstracts", of the individual pieces of research, are prepared and published. The most used set of summaries in English is known as "Chemical Abstracts", published once a fortnight by the American Chemical Society. There are two other important abstract journals—our own "British Chemical Abstracts" and the German "Zentralblatt". Short summaries of your account of methyl sodium would appear in these abstract journals, which also say where you published your original work, so that anyone interested can read it in full.

The authors of comprehensive chemical treatises get their information from the abstract journals, referring to the original papers where necessary. Those who write less comprehensive books get their information from the treatises and so on, until finally only the fundamentals of chemistry appear in elementary text-books, and methyl sodium not at all.

The research chemist, to keep abreast of his subject, must comb through the "abstracts", making a note of those papers which interest him and reading them if he can. He must, therefore, be able to read chemistry in languages other than his own. German and English are essential, because most early work and comprehensive chemical treatises are in German, and the greatest bulk of modern work is published in English. French is useful, Russian is becoming important, Italian and Spanish are not difficult with a dictionary. Chemists in most of the smaller countries publish their work in English, German, or French. Rarely has the author found a paper in Japanese he would have liked to read!

Now let us consider how you set about becoming a research chemist or, in fact, any sort of chemist. The main educational ladder is quite straightforward and definite, leading to an Honours degree in Chemistry or equivalent qualification—and you must qualify. At the age of 16 you must pass the General Certificate of Education at Ordinary level in a suitable choice of subjects. Chemistry should be one subject, but your headmaster will give guidance as to which subjects are necessary and desirable. Thus, Latin is not necessary for a study of chemistry, but is essential for anyone wishing to enter Oxford or Cambridge University and is best taken at this stage. You continue your studies at school to take the General Certificate at the Advanced level. It is important that you do very well in chemistry in this examination. Now it is best to go to a university to take an Honours degree in Chemistry, but it is probable that your parents cannot afford to send you, so you must attempt to take a scholarship. Some—i.e. the State and County scholarships—are awarded on the results of the General Certificate examination in papers at Scholarship level; others on the results of special examinations set by the universities or colleges concerned. Your headmaster again can provide the information and guidance you need regarding university scholarships.

Once you have gained admittance to a university, the objectives are again clear. Your tutor or director of studies will guide you through the various courses until you graduate, i.e. take your Honours degree, B.Sc., or B.A., after three or four years at the university.

If you have obtained a first-class or good second-class degree all is well, otherwise you cannot be advised to continue with the idea of becoming a research chemist, but there are equally good opportunities for chemists in work other than research. There is the possibility of a good career in Chemical Industry provided you have other valuable personal characteristics, and you should enter the industry straight away. If your degree is satisfactory you now need training in research methods, and this is best acquired at the university.

The university teachers will each be engaged in chemical research, so, having decided which research interests you most, you approach the teacher concerned, usually your professor, with the object of becoming one of his students and doing research, often under his personal supervision. This usually entails finding more money for fees, but many research grants are now available and are often awarded on the result of the degree examination. Application for a grant has usually to be made before the degree examination, so it is best to approach your prospective research supervisor early in the final year of your undergraduate course, and he will help you over this hurdle if he accepts you as a possible research student.

You carry out research under his guidance for two to four years, according to the university and your ability, then submit a written account of the work for the degree of Ph.D. (D.Phil. at Oxford), meaning Doctor of (Natural) Philosophy, and, if successful, leave the university entitled to call yourself "doctor" and with a recognized qualification of having been trained in the methods of chemical research.

Nothing has been said about National Service. Some prefer to do it between leaving school and starting at the university, others at the end of the university course, but regulations regarding this phase of your career are subject to change and it need not be discussed at length.

How should you choose your university? You may prefer to go to the same university as your father or chemistry master did, but there is no question that all universities are not equal in the quality of their teaching. If you choose one which has a vigorous research school producing a steady stream of publications of fundamental chemical research, you cannot go far wrong. Judge the university chemical school on its present, rather than its past. If you wish to study chemistry as applied in one of the technologies, this may limit your choice to one university, e.g. Sheffield for Glass Technology, Birmingham for Malting and Brewing. Those who receive State Scholarships are directed to a university.

The most difficult step in this educational ladder is the scholarship linking school and university. Suppose you do not obtain it, need you give up the struggle? Although your chances of reaching the highest flights of fundamental research are blighted by this failure, there is no need to abandon a research career. Your alternative is to enter the laboratory of some progressive chemical company as a laboratory assistant; then, by evening study, follow courses leading to an external Special degree of the University of London or to the Associateship of the Royal Institute of Chemistry. It is the hard way, but many famous industrial chemists of the past have followed it, and now it is much easier than it was only twenty years ago. Many chemical companies allow time off—up to one day a week—and pay the fees and perhaps travelling expenses of young employees whose studies are progressing satisfactorily. This allowance is often made to age 21 or even later in certain circumstances. Some companies give training classes on their own premises. After taking an external degree you may, if you are lucky, be able to enter a university as a research student and take your Ph.D., or you could take an external Ph.D., or become a

Fellow of the Royal Institute of Chemistry. Facilities for the more advanced study necessary to take these qualifications may be difficult to find, however; and so far as it concerns your employer who now knows your potentialities the Ph.D. is not a necessary qualification and will make little difference to the work you are doing for him or to your salary. Its only value to you arises if you desire to change employers.

It should be explained that the Royal Institute of Chemistry is the professional society for chemists in this country; all its members, except students, are qualified chemists. It admits only those who have passed its own qualifying examinations or university examinations at a sufficiently high standard. There are two grades of professional membership, the lower is the Associateship and the higher the Fellowship, indicated by the initials A.R.I.C. and F.R.I.C. which members may put after their names.

What qualities do you need to become a research chemist? First and foremost, an intense interest in chemistry. This provides the driving force necessary to maintain you on a course of learning such as the above, which may entail giving up much of your leisure time for about six years after you leave school. It also provides the curiosity necessary to keep you working often for long hours at fundamental research. You also need to reach a first-class or good second-class Honours degree standard in order to understand and follow the advances in your chosen part of chemistry, as well as to make original contributions to it. These two are not enough, however, for chemistry is essentially an experimental science, and manual dexterity and infinite patience in planning and carrying out experiments are also necessary. Persistence of effort and restless curiosity characterize the born research worker. Into these essential qualities are blended your own characteristics which determine whether you will do fundamental, or applied research work as a member of a team or as a lone worker, doing all the experiments yourself. These qualities largely determine your future.

Having become a research chemist, what prospects open up before you? If you are especially interested in fundamental research and like teaching, you will try to become a university teacher, and the summit of your profession is the professorial chair. If you do not like teaching your alternative is a fundamental research appointment in industrial or research association laboratories. If your interest is in applied chemistry you will obviously enter industry or the Ministry of Supply and would probably find it profitable to study Chemical Engineering to implement your knowledge of chemistry. The tastes of many research workers change as they get older; they become less interested in fundamental research and more interested in applied research, or cease to be interested in research altogether. Industry provides greater scope for these more restless souls, and there is no industry in which chemistry does not play a part. Chemistry is essential to modern living and whatever part you play in it, great or small, you have the satisfaction of knowing it is a useful—nay indispensable—job in our over-populated land.

# Have You a Monkey in Your Family Tree?

G. J. BOLTON

THOSE of us who have to travel daily on a bus or in a train will be uncomfortably aware that we are not alone on this earth. We share it with numerous fellow creatures and with plants and trees as well. Have you ever thought how plants and animals began their life on Earth? Were they all created in one week or have the millions of species of plants and animals become what they are now by a series of slow changes from a common ancestor? If you were able to examine your own ancestors and the ancestors of the monkeys you would eventually come to a point as you went further back in time where you and the monkeys were the same species. Perhaps it is some consolation that this common ancestor existed probably more than 500 million years ago.

This is the general idea of evolution; it implies that no new species has ever been created but that all have evolved by a series of changes from a common ancestor. What evidence have we to support this sweeping claim, which was first to make an impression on the world in 1859 when it was put forward by Charles Darwin in his book, "The Origin of Species"?

The first evidence, and probably the most important, lies in the fossil record. Fossils tell a story which is still being gradually unfolded by the geologists as they continue to find in the rocks of the world new skeletons and shells of animals which once inhabited the Earth but which have been extinct for millions of years.

Secondly, there may be some evidence to show that we all have a common ancestor when we compare the limb bones of different species of animals and find that their arrangement is similar. This suggests that the species are related.

Thirdly, something can be learnt from studying the embryos—the unborn young—of various species. They have marked similarities which disappear as the embryos develop. For instance, you had gills just like a fish some time before you were born. We can only assume that this is a relic of the days when fish were the most advanced animals living and gill breathing the highest development.

The geologists have discovered that the Earth's crust is made up of a series of deposits generally speaking laid down one on top of the other, the older ones at the bottom and the more recent ones nearer the surface. In the course of time these deposits have been folded by earth movements, cracked and broken, altered by high pressure and temperature, and many of them washed away or eroded. In spite of this it is still possible to arrange them in the order in which they were deposited. From these deposits it is possible to obtain fossils of the animals living at the time when the deposits were formed. These deposits have been classified and named; a glance at the table of geological history will help you to understand this. The oldest deposits are at the foot of the table and the more recent ones at the top.

The earliest deposits were laid down 400 to 500 million years ago. Much of them has been either washed away or so distorted that most of the fossils in them have been destroyed. Those that remain tell us, however, that at this time there were only Invertebrates living on the Earth, although these were mainly soft-bodied animals with no skeleton (so we have no fossil record of them). Some of them, however, had hard shells which have been preserved in the rocks; and we are able to get some idea of the population of the seas at that time, for in the deposits of the end of this period and of the beginning of the Silurian period the fossil remains of the earliest fish are found.

| PERIOD | ESTIMATED TIME SINCE BEGINNING OF PERIOD IN MILLIONS OF YEARS | | NOTES |
|---|---|---|---|
| PLIOCENE | 10 | AGE OF MAMMALS | |
| MIOCENE | 17½ | | |
| OLIGOCENE | 30 | | |
| EOCENE | 50 | | APPEARANCE OF PRIMATES |
| CRETACEOUS | 100 | AGE OF REPTILES | FIRST TRUE FLOWERS APPEAR |
| JURASSIC | 130 | | ARCHAEOPTERYX, OLDEST BIRD FOUND |
| TRIASSIC | 175 | | MAMMAL LIKE REPTILES |
| PERMIAN | 215 | AGE OF AMPHIBIANS | OLDEST REPTILES APPEAR<br>WIDE VARIETY OF AMPHIBIANS |
| CARBONIFEROUS | 300 | | FORMATION OF COAL MEASURES |
| DEVONIAN | 350 | AGE OF FISHES | GREEN PLANTS WITH ROOTS & STEMS |
| SILURIAN | 390 | | EARLIEST FISH |
| ORDOVICIAN | 480 | AGE OF INVERTEBRATES | EARLIEST CHORDATE |
| CAMBRIAN | 500 | | |

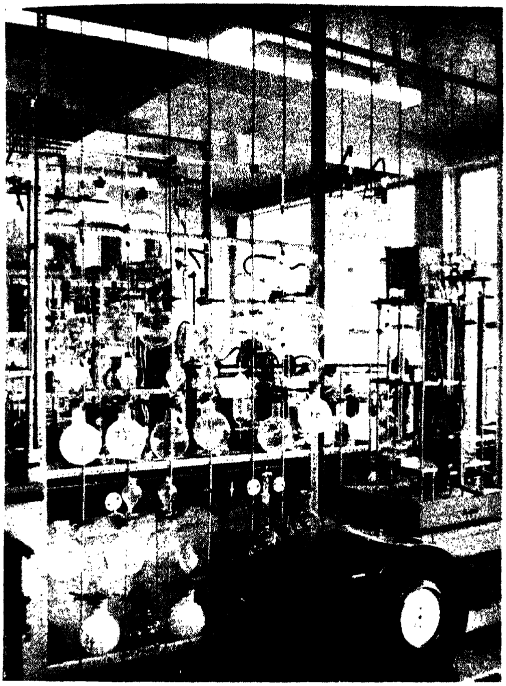
Geological Table.

These fish are our first example of a Vertebrate or backboned type of animal, and from now on the fossil record is much more complete. The reason for this is that vertebrates are much more easily preserved. They have hard skeletons, teeth, and often armour plate like our modern tortoise, and all these fossilize easily.

What are the differences between the vertebrate and invertebrate types of animal? Both types still exist today. Look at a codfish on the fishmonger's slab; it has bilateral symmetry, that is to say that one side of its body is the mirror image of the other. This is connected with the fish's activity, with its ability to move generally in one direction in search of food. Compare this with a jelly-fish, an invertebrate animal with no backbone; it has radial symmetry, with a mouth in the middle of its body. This arrangement is satisfactory for an animal which does not move in search of food but which floats about or rests on the sea bed, eating whatever happens to pass its way. However, it is not hard to see that the arrangement found in the codfish is much more efficient, in as much as it extends its feeding range.

All vertebrates, of which the codfish is but one example, have an internal skeleton (made of bone or cartilage) the main parts of which are a backbone running the length of the back, and ribs attached to the backbone. At the front end of it is some sort of skull enclosing the brain. Most vertebrates also have two pairs of limbs. In the fish they are fins, in most land animals they are legs, and in man they are arms and legs. Inside the backbone and protected by it, the vertebrates have a main nerve trunk called the spinal cord. The nerves send the messages from the sense

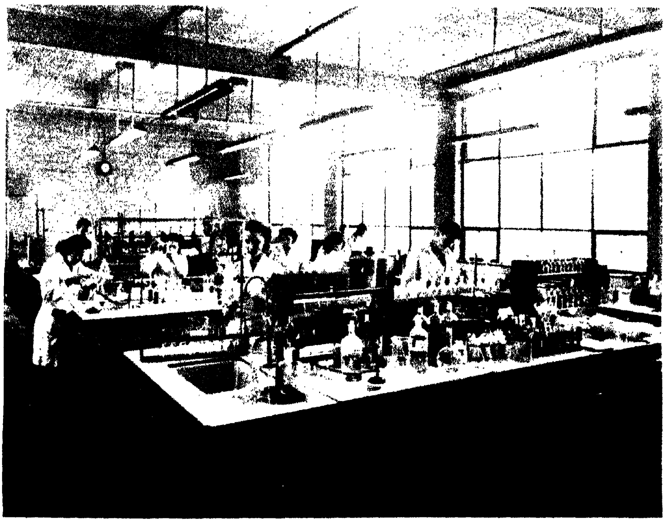
## PLATE III. THE RESEARCH CHEMIST



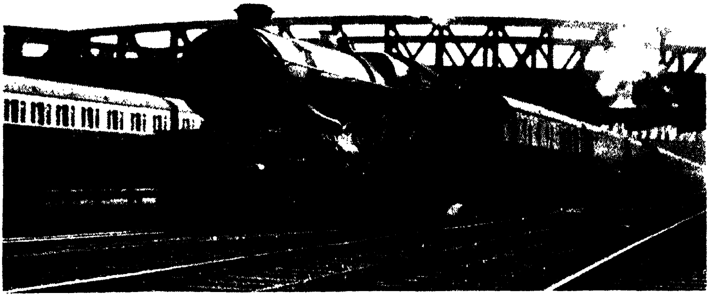
Equipment used in hydrocarbon research.

*(Both pictures by courtesy of I.C.I. Ltd.)*

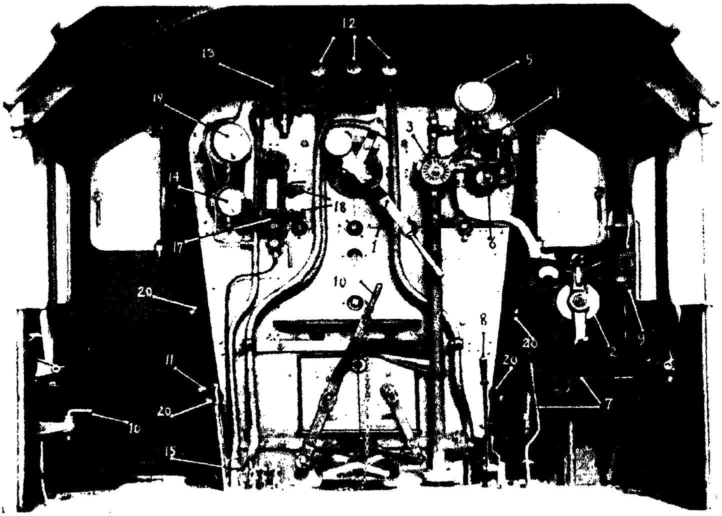
Dyestuffs research laboratory



# PLATE IV. PASSENGER LOCOMOTIVES



"Cornish Riviera" express leaving Paddington



Cab-fittings of a "Castle" class locomotive

*Driver's Fittings.*

1. Regulator.
2. Reversing screw and handle.
3. Vacuum Brake handle.
4. Steam ejector handle.
5. Vacuum Brake gauge.
6. Blower valve.
7. Sanding gear levers.
8. Cylinder drain cock lever.
9. Automatic train control apparatus (used on (ex) Great Western Railway only.)

*Fireman's Fittings.*

10. Firehole door lever.
11. Injector water valve.
12. Injector steam valves.
13. Train heating steam valve.
14. Train heating steam gauge.
15. Dampers.
16. Coal watering hose cock.
17. Water gauge.
18. Water level test cocks for use if water gauge fails.
19. Boiler pressure gauge.
20. Wash out plugs.

*(Photos by courtesy of British Railways)*

organs such as the eyes, nose, or tongue to the brain, where they are sorted out and the appropriate action is signalled.

A study of the sense organs can throw some light on our evolutionary history. In some of the earliest fish skulls we find a socket in the middle of the top of the head. This probably contained a third eye. If we examine the brain of a present-day vertebrate, including man, we find a small swelling called the Pineal body. This is the relic of the third eye. We think of our ears primarily as organs of hearing but in fact they perform an important function in giving us a sense of balance. This function is probably the earlier of the two. The primitive ear found in the fish is used to give a sense of balance and to detect sound vibrations in the water. In land vertebrates this has been retained and is known as the inner ear. In addition, of course, vertebrates possess the external ear which is used to pick up sound waves.

All the vertebrates possess some sort of breathing organs. The primitive vertebrates were water-living fish which obtained their supply of oxygen from the water by means of gills. The land types developed lungs which enabled them to obtain oxygen from the air. The development of lungs was a major step in the conquest of the land. Obviously, until lungs were developed it was impossible for any vertebrates to live out of water. All vertebrates too have a closed blood system. It consists of a heart and blood channels, the arteries and veins which carry blood to and from the limbs. In these vessels blood circulates, carrying oxygen to the muscles and transporting food in solution round the body.

Knowing the fundamental characteristics of a vertebrate animal and knowing that vertebrates fossilize more easily, we can examine the fossil record of any particular period and see if there is any connection between one kind of fossil and another. If there is, we can suspect that one developed from the other.

Up to the beginning of the Silurian period we have no evidence of any vertebrate life. We must assume therefore that the Earth was populated by invertebrate animals of which little trace is left. At some point it seems likely that an invertebrate group developed an elementary backbone, but we do not know when this happened. In Silurian times the primitive fish had begun to inhabit the Earth, but these fish were in many respects very different from the scaly finned creatures we know today. They were armoured with thick plates of bone which covered the outside of the head, trunk, and tail. The plates were solid on the head, and flexible on the trunk and tail to allow the animal to swim. The plates have earned the group the name of *Osteocoderus*, which means shell-skinned. The only group of fish living today with which they can be compared is that of the lampreys. The ancient fish resembled the lampreys in having no jaws; the mouth was merely a hole or slot and they fed by burrowing along the surface of the mud. The absence of any paired fins or limbs is a further pointer to the extremely primitive organization of these animals. You may be wondering why the earliest fish required this armour plating. It seems to have been necessary as a defence against enemies. At this stage, of course, they could have no vertebrate enemies, but we find fossil remains of giant water scorpions which lived at the same period and attacked these fish. Later, fish increased in size and they swam faster, but the water scorpions decreased in numbers and eventually died out. At the same time there was a reduction in the armour plating of the fish. In the course of time some of the plates seem to have sunk into the body, to be covered by a layer of skin. The human skull is one example of this.

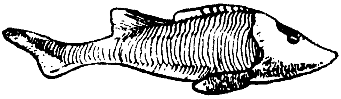


Fig. 1. *Cephalaspis*—an example of a shell-skinned fish.

So, in tracing the process of evolution, we come to the Devonian period, estimated at some 350 million years ago. Two marked developments from their ancestors are shown by the fossilized fish of this period. The Devonian types have paired fins and jaws and can be compared with our sharks of today. An example of a Devonian fish is *Cladoselache*, seen in Fig. 2. The jaws probably developed from a slight alteration in the gill bars. The fins probably started as flaps of skin extending from the body. It is worth while noting that the paired fins of all fish are not used to propel the fish through the water. The forward movement is provided by the waving of the body and the tail from side to side. The paired fins are used only for steering the fish, par-

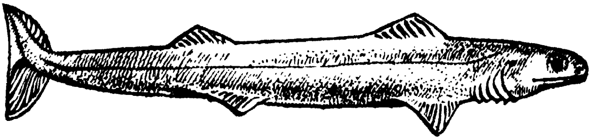


Fig. 2. *Cladoselache*—one of the first fish with jaws and paired fins.

ticularly up and down, like the hydroplanes of a submarine.

After the jaws and fins, fish developed lungs towards the end of the Devonian period. This was a most important advance, as it made living on land a practical possibility. Why did the lungs develop? The climate of the Earth may have been the reason. During the Devonian period there were rainy seasons followed by times of severe drought. Fish without lungs would be unable to survive in the stagnant pools which had all but dried up, whereas the more fortunate possessors of lungs could come up to the surface and take a gulp of air, obtaining a supply of oxygen from it. Later in the period the climate appears to have become more settled and the lungs less essential for survival. So it became an air sac which could be filled with air to increase the buoyancy of the fish and help it to the surface. This organ survives in our modern fish and is known as the swim bladder. There are today only three forms of lung fish left, one in Australia, one in Africa, and one in South America. These are all regions of occasional drought and therefore the presence of lungs may be essential for survival. An example of one of these air-breathing fish is *Protopterus*, seen in Fig. 3.

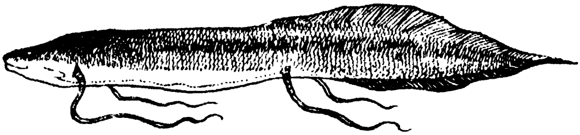


Fig. 3. African lungfish (*Protopterus*)—an air-breathing fish.

At this stage of evolutionary history our most advanced vertebrate has now acquired most of the essentials for a life on land, namely the lungs, a bone skeleton for supporting the body, and rudimentary limbs for moving the body. Now we first meet a large and important group of animals, the Amphibia. Their name means that they are able to live both on land and in water. A common example of a modern amphibian is the frog. By studying the life history of a single common frog we can get a good idea of what probably happened in evolutionary history. The eggs are laid in water, for the amphibia have not succeeded in becoming wholly land dwellers. The egg hatches out into a tadpole which is compelled to live in water. It has no lungs but breathes by means of gills in the same way as a fish. It has no limbs but swims by means of a tail which it waves from side to side just as the fish does. After some weeks hind-limbs are formed; they grow out from the

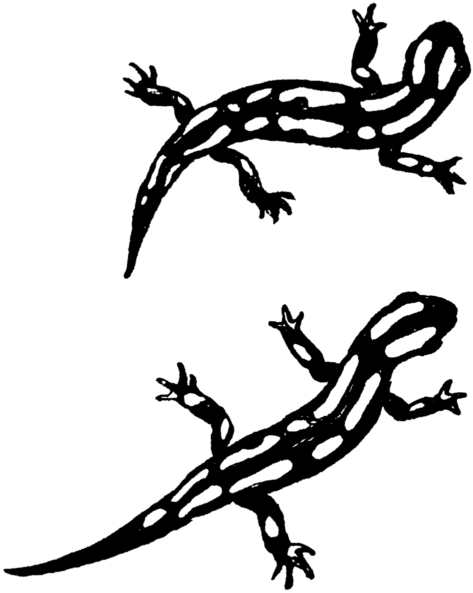


Fig. 4. The gait of the salamander—note the fish-like sinuous curves of the body.

base of the tail. Later fore-limbs develop. Simultaneously lungs are formed and our fish-like tadpole is now ready to start a land life, which it does as a frog, the only major change which takes place on land is the resorption of the tail into the body. Here on a small scale is a picture of the whole process of the evolution of the amphibia from the fish.

Two other modern amphibians are the newt and the salamander, and they give away their fishy ancestry by their method of progression on land. The fins of the fish have been changed into limbs, but they are small and feeble and cannot lift the animal off the ground. The legs move easily but as they do so the body is bent in curves just like the body of the fish when swimming. These limbs in early types of amphibia, although small and feeble, had already the bone pattern typical of land animals.

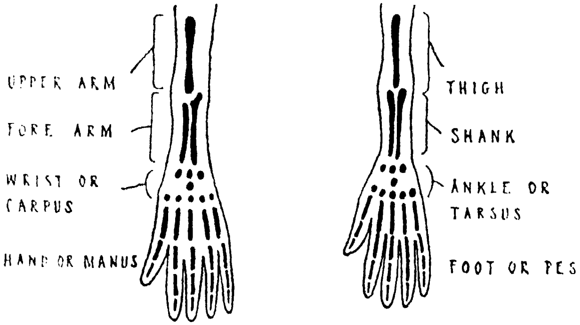


Fig. 5. Diagram of the five-fingered (Pentadactyl) limbs of the early Reptiles.

Although the amphibia were the first vertebrates to conquer the land and although they were once highly successful organisms, they have now shrunk to a small and insignificant group of land animals. This is what we would expect, as they never got beyond being a rather special type of fish which could walk and breathe on land. Their great importance lies in the fact that they are the forerunners of all our four-legged land vertebrates. Towards the end of the Carboniferous period the earliest Reptiles began to inhabit the forests and swamps which covered the Earth at that time. One of these, the *Seymouria* (Fig. 6), was very like an amphibian to look at but, in common with other reptiles, it had freed itself from living in water at all stages. In the reptiles we find the first land egg. For a land egg to be successfully matured it must contain within it all the essentials for life that the fish and amphibian eggs are able to obtain from water. As this reptilian egg set the pattern for all future land eggs it is worth a little consideration. It contained a large yolk which acted as a food supply for the young animal. It contained a sac filled with a liquid which surrounded the embryo or young animal and prevented it from drying up and protected it also from shock in case of a jolt. It is this liquid-filled sac which takes the place of the pond water required for the amphibian egg. In addition the reptilian egg had a porous shell through which a supply of oxygen was obtained. The amphibian egg obtained its oxygen from the water in which the egg was laid.

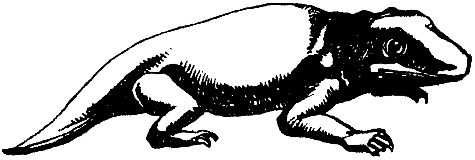
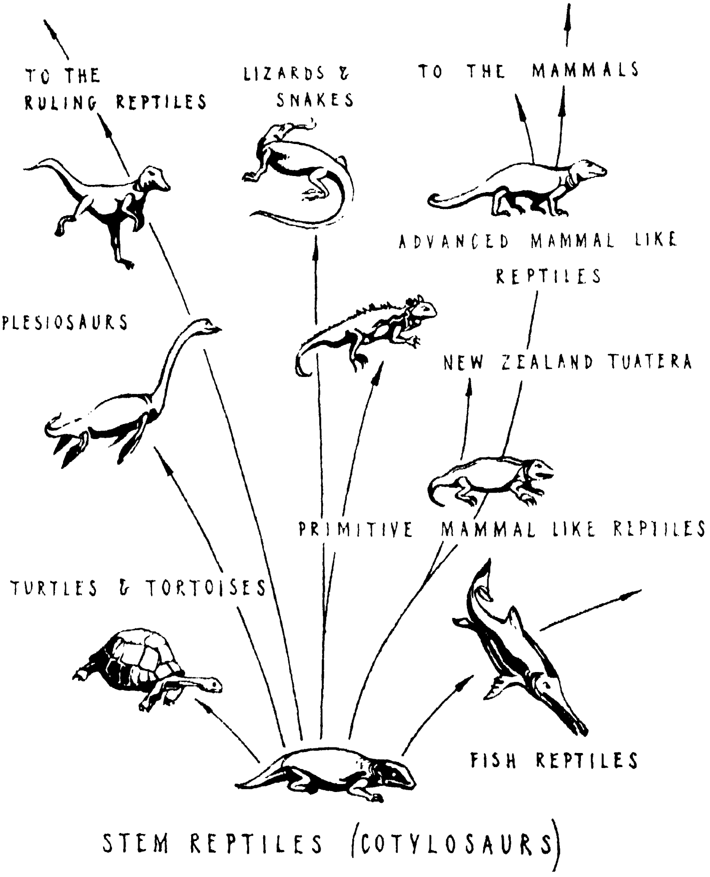


Fig. 6. *Seymouria*—one of the earliest Reptiles.

The perfecting of the land egg freed the reptiles from water, and steadily their body structures improved for life on land. As these improvements continued a wide



FAMILY TREE OF THE REPTILE

Fig. 7.

variety of reptiles appeared; their fossilized remains are found in the rocks of the Age of Reptiles (see the Table). You will get an idea of the variety of reptile types from Fig. 7, which shows the forms of reptiles which developed from *Seymouria.* In the reptiles there developed a great advance in the skeleton, and with it many improved methods of locomotion. The earliest land animals walked with their limbs "spread-eagled" on each side of their bodies—a modern example is the turtle. It is not difficult to see that this method of walking needs considerable muscular effort to lift the body off the ground. To improve this method of moving about, it is necessary to tuck the limbs underneath the body until, when the animal is standing, the two pairs of feet are vertically below the shoulder joints and hip joints respectively. This is precisely what happened during the evolution of the reptile forms. Not only were the feet tucked further under the body, but one group, the Ruling Reptiles or Archosaurs, developed a bipedal gait. In other words they occasionally walked or probably ran on their hind legs. If you look at Fig. 8 you will see *Ornithosuchus* as an example of this. You will see that when walking it probably had its fore-feet on the ground but when in a hurry and running the shortened fore-limbs and feet were lifted off the ground and the weight of the fore-part of the body was counter-

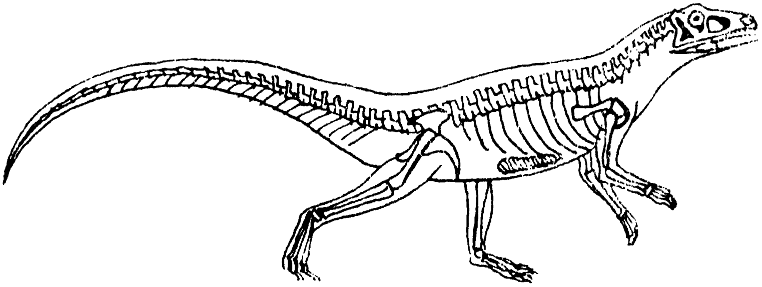


Fig. 8. *Ornithosuchus*—a Reptile which sometimes walked or ran only on its hind legs.

balanced by a long, heavy tail. This advance is important, as the fore-limbs were freed from carrying the weight of the body and could be put to other uses. In some reptiles hands began to develop, and twice during the history of the reptiles wings appeared.

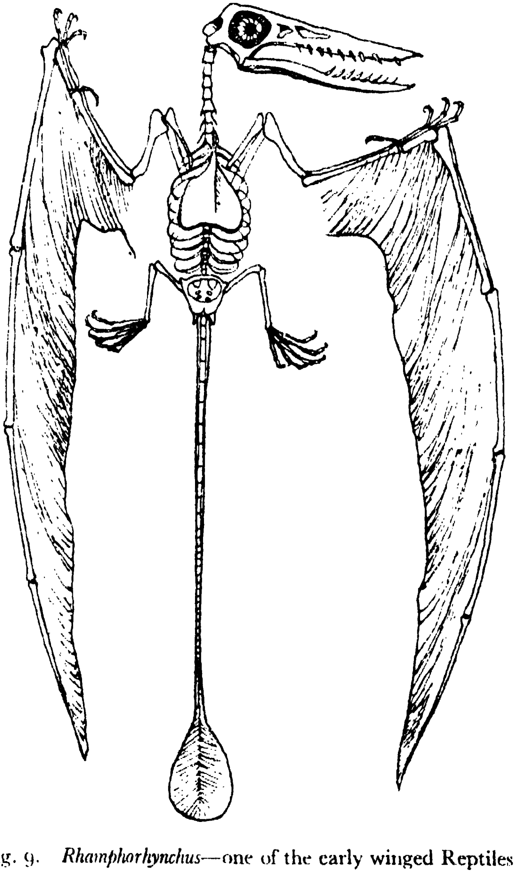


Fig. 9. *Rhamphorhynchus*—one of the early winged Reptiles.

One of the winged reptiles was the Pterodactyl or wing-fingered reptile. This was very different from our modern bird. It had no feathers but just a web of skin held out by the bones of the fore-limb. It had a long beak with teeth, a short body, and a long tail with a rudder on the end. If you look at Fig. 9 you will see the skeleton of one of these strange beasts. In addition to these winged reptiles we find in the Jurassic rocks the fossil remains of *Archaeornis* (Fig. 10), which is one of the earliest birds as we know them. The skeleton was very similar to the modern bird skeleton but it still had a long reptilian tail with a double row of feathers on either side. The wings were feeble and it had not developed the keel or breastbone, showing that its powers of flight were limited. Nevertheless the skeleton of this animal is sufficient evidence to proclaim it as the forerunner of our modern birds. At the same time its long beak and teeth and the long tail show that it is not far removed from the reptiles. Other reptiles which developed at this time and have survived up to the present day are the lizards, the snakes, and the turtles.

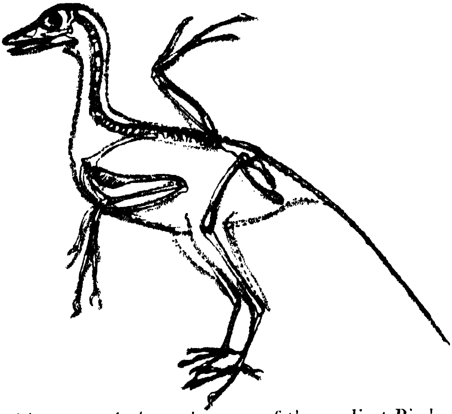


Fig. 10. *Archaeornis*—one of the earliest Birds.

At one time, then, in the Earth's history, the reptiles were a most successful group; from them developed the

Mammals, of which Man is a member, and the improved organization of the mammals enabled them to oust the reptiles from their dominating position. Do not imagine, however, that the evolution of the mammal began at the end of the Age of Reptiles. The earliest mammal ancestors appeared almost at the beginning of the reptile age, but it was a very long time after this early start that they were able to dominate the reptiles. The reason for their success lies in their great adaptability. We find today a wide variety of mammals, all differing very considerably in body form and organization, although they have all developed from the same original stock.

As we ourselves are members of the mammal group it is perhaps worth pausing for a moment to consider the features common to all mammals before discussing the different types that share our Earth with us. First, the name "mammal" means an animal which nurses its young. That is to say, in the first weeks of its life it feeds entirely on milk supplied by the female parent. With the exception of two very primitive mammals the eggs are no longer laid and incubated but they are retained in the body of the female. They start their early development there and the young are born alive after a varying period of development, well protected by the body of the mother. In the case of rats and rabbits development is very rapid, about 6 weeks; in humans it is much longer, about 40 weeks.

Warm blood is a feature of all mammals and birds. This is a great advantage, as the normal activities of the body can continue at about the same rate all the year round. Cold-blooded animals such as the frog are slowed down by cold and they are forced to hibernate or go to sleep for the whole of the winter. The warm-blooded animal has an efficient heart and vessels to carry the blood round the body. In order to retain the warmth in the body the skin is covered with hairs. In man the wearing of clothes has reduced the need for a thick covering of hair. The only disadvantage of having warm blood is that heat is being lost to the surroundings all the time and therefore a considerable quantity of the food eaten is used up in keeping the body at a fairly constant temperature; the remainder is available for bodily activities such as walking or running.

The brain and skull of mammals are much larger than that of any of the reptiles. This is a most important advance, as it allows for improvements in the nervous system and better senses of sight, smell, and hearing. The larger skull and brain have enabled man to develop the power of reasoned thought and have led him to a dominant position in the animal kingdom. It is certainly not his physical size and stature which has given him this command, for his body is relatively small compared with some of the large modern animals, the elephant or the rhinoceros.

Modes and speeds of movement have considerably improved in the mammals. The main difference in the skeleton is in the position of the knees and elbows relative to the body. In our early slow-moving reptiles the knees and elbows pointed outwards in an unsatisfactory position for carrying any weight. In mammals the knees point forwards and the elbows back. This is a much more efficient arrangement, as all the energy exerted by the muscles is used in propelling the animal forward and little is used in supporting the weight of the body. A horse, for instance, exerts little muscular effort when standing still. The limbs act as struts supporting the body and scarcely any muscular effort is required to maintain the position.

Now that we have an idea of what we mean by a mammal let us look at some of these advanced animals. One of the earlier groups is that of the Carnivores or flesh-eaters. Their ancestors were insect-eaters and it only required a little increase in size and better teeth capable of piercing hide and cutting bones for an insect-eater to develop into a flesh-eater. This is what must have happened; so we get our modern cats, dogs, bears, and other animals that live on a diet of raw meat when they are not domesticated.

At about the same time as flesh-eating mammals developed, another great group appeared, distinguished by its hooves instead of the usual five toes. This group preferred to eat grass rather than flesh and as a result it developed flat-topped grinding teeth in order better to chew the vegetation. To escape their enemies these animals grew capable of moving at high speeds. This was achieved by the shortening of the upper bone of the leg and by the reduction in the number of toes. The horse is a very good example of this type of animal. The earliest known horses had five toes. At a later date the two outside toes shortened so that they did not touch the ground. Eventually the shortened toes disappeared and a type of horse with three toes developed. The process continued; the two outside toes shortened, giving us the modern horse which may truthfully be said to walk on its middle fingers and toes only. It sounds very uncomfortable to us but we must admit that it has resulted in a very fast means of progression.

There are many groups of mammals but one of the most successful so far evolved is the rodent or gnawing animal like rats, mice, and rabbits. They thrive in all parts of the Earth and have adapted themselves readily to all sorts of conditions. They all possess very sharp cutting teeth in the front of the mouth and it is this characteristic which has made them a pest to man, because they can cut through wood and enter houses and grain stores.

The whales are another unusual group of mammals, for they have adapted themselves to a return to the sea. They obtain oxygen from the air instead of from the water but otherwise they have once more become very much like fish. They have lost their hairy covering and their land limbs have become fins again, although the mammal bones are still retained inside the fins. Although the mammals are mostly land animals, the whale shows us that mammals have their representatives in the sea.

Mammals also have an aerial member, the bat. The wing of the bat is quite different from that of a bird. It is simply a web of skin stretched over the elongated fingers of the hand. The thumb is left free for grasping and the skin is stretched over the other four fingers. Mammals have adapted themselves, as we now see, to life on the land, in the sea, and in the air.

At this stage we can begin to look for a clue to the appearance of Man. Man is a member of the group of mammals known as the Primates, and the fossil record of this group is regrettably poor. It is not until the Eocene period that fossilized primate remains are found. The living primates are divided into three groups, the Lemurs, the Tarsioids, and the Anthropoid or man-like apes. The first two groups do not concern us here, but a glance at Fig. 11 will show you where they fit into evolutionary history. The anthropoid apes

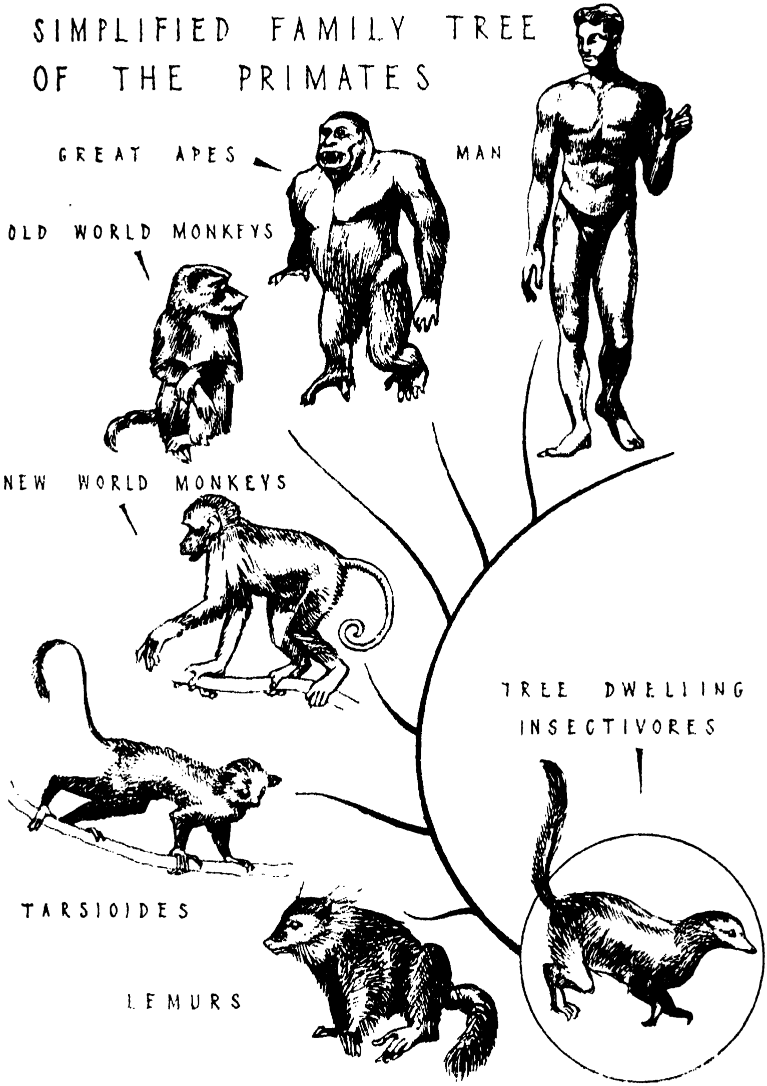

SIMPLIFIED FAMILY TREE OF THE PRIMATES
GREAT APES
MAN
OLD WORLD MONKEYS
NEW WORLD MONKEYS
TREE DWELLING INSECTIVORES
TARSIOIDES
LEMURS

Fig. 11.

are an important group. There are four living groups of man-like apes today, the Gibbons, the Orang Outangs, the Chimpanzees, and the Gorillas. They all have skeletons similar to that of man. The chest is broad, the fingers are long in relation to the thumb, the arms are rather long, and the legs are short. These features help the animals to move by swinging from tree to tree instead of walking on the ground. Furthermore the toes of the feet of these animals are still able to grasp and cling on to trees—unlike the toes of man. When the fore-limbs are much longer than the hind-limbs these apes have to hold their bodies in a semi-erect position when they walk on "all fours". So these animals demonstrate the beginnings of the fully erect posture of man. If we compare the structure of the bodies of anthropoid apes with that of the human body we find that the differences are very small. The bones and muscles differ only in their relative sizes. In all other respects every bone and every muscle in the body of an ape has its counterpart in the body of man. The important differences lie in the method of movement and in the size of the brain.

The upright two-legged walk of man seems to have reached its limit of development. It has brought with it an alteration in the foot. The grasping foot of the ape is useful in trees but it is a clumsy structure for walking on and for supporting the whole weight of the body. In man therefore the toes are much reduced and the big toe has come into line with the others instead of projecting to be used like a thumb. The teeth of man are smaller and the mouth and jaws do not protrude as far as in the apes. This may be due to a greater use of the hands in feeding.

Most important of all is the great development in the size of the brain, which in man is two or three times that of the apes. The high forehead and the larger fore-brain in man differ markedly from the receding forehead of the ape. It is this advance in brain capacity that has given man his dominant position over the remainder of the animal kingdom on the Earth today.

You certainly have a monkey in your family tree but you have many other types of organisms there too. Man is the most advanced creature yet developed; he is perhaps the first creature able to realize the fact that he has developed. Is there anything to suggest that this development of man is complete? As we have seen, other dominant forms have appeared on the Earth from time to time—and in turn each has been superseded. Will man be superseded too? Or can man with his steadily growing knowledge of the world hope to direct his own evolution? These are questions which we cannot yet answer though future biologists may hope to do so.

## HEAT FROM CEMENT

As cement sets the calcium silicates and aluminates which it contains combine with water to form hydrated crystals; other chemical reactions occur as well. Most chemical reactions are accompanied by measurable heat changes, and the setting of cement is no exception, though it is not spectacular. However, when concrete sets enough heat is liberated to cause engineers to make allowance for it. As the concrete Boulder Dam was built 750 miles of cooling pipes had to be laid in it—otherwise it would have taken 200 years to cool down!

# A Day in the Life of a Passenger Locomotive

R. W. FITZHUGH

THE first person to be engaged in preparing the engine for its day's work is the firelighter, who, after making sure that there is sufficient water in the boiler, puts a shovelful of burning coals, often from the furnace where the sand is dried, into the firebox. On top of this he places some chunks of wood, usually pieces of old broken sleepers, probably some used cotton waste, and finally some coal from the engine's own tender. The fire is not made up too quickly, as this would produce unequal expansion of the various parts of the boiler, which would in turn tend to cause leaks. When the steam pressure has risen sufficiently the blower is turned on. This is situated under the chimney and consists of a small nozzle or a ring of small nozzles from which steam is ejected. The jet of steam rushing

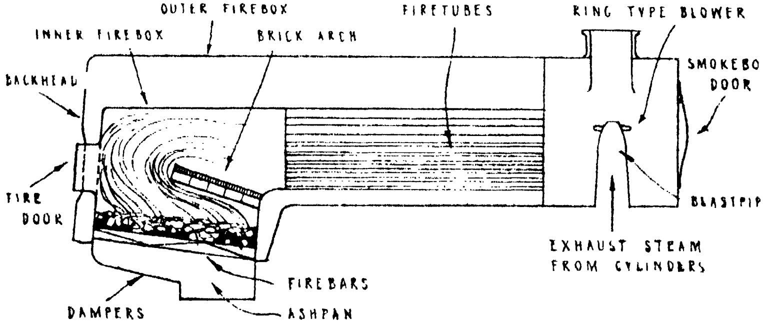


Fig. 1. Diagram of a locomotive boiler.

through the chimney produces a partial vacuum in the smokebox, and this causes a current of air to be drawn through the fire as shown in Fig. 1. When the engine is running the exhaust steam from the cylinders passes through the blastpipe nozzle and has a similar effect.

The driver and fireman usually book on about three-quarters of an hour before the engine is due to leave the shed. Their first duty is to look at the notices which give details of any "slacks" due to repairs to the track, bridges, and tunnels, or to slips in embankments and cuttings, often caused by mining under the railway. There are also listed any alterations to track layout and signalling arrangements. They then proceed to the stores, from which they collect supplies of oil and cotton waste.

When they reach their engine the driver makes a thorough examination to see that it is in good running order. The fireman tests the injectors, which force the water from the tender into the boiler. He then makes sure that the passages in the water-gauges are clear (two are usually provided in case one fails). This clearance is most important; if the gauges were blocked they would not give a true indication of the water level in the boiler, and if the level were to fall below that of the firebox crown, the firebox plates would become intensely hot and buckle—and a boiler explosion might occur. A water-gauge is blown through by opening cock C (see Fig. 2) and by closing cocks A and B in turn. If the passageways are clear, steam is blown out with cock A open, and water is blown out with cock B open. On restoring the cocks to their normal positions the water level in the gauge glass should rise to its former level.

The fireman has to make sure that the smokebox door is tightly closed, since if air leaked through into the smokebox the partial vacuum would be destroyed, and the fire would not "draw" properly. He then checks the amount of water in the tender and, if necessary, he trims the coal and breaks up any large lumps. The engine is then ready to proceed to the station and on to its train, the coaches of which have already been cleaned and examined. The guard tells the driver how many vehicles are on the train. The engine is immediately coupled to the train and the brakes are tested. The guard then makes sure that a tail lamp is fixed on the last vehicle, that the vestibule doors at each end of

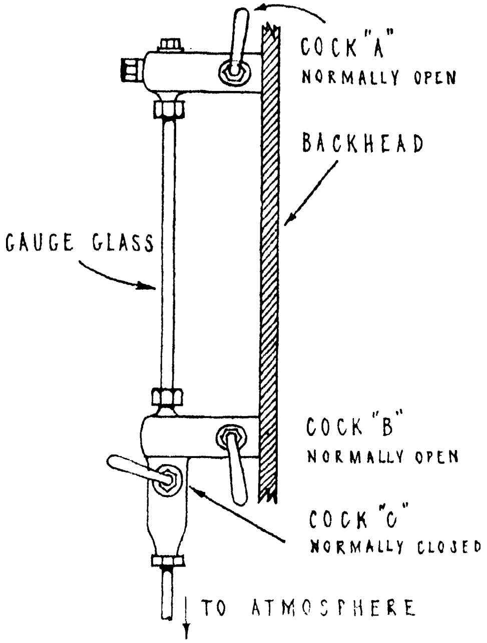


Fig. 2. Diagram of the water-gauge.

the train are locked, and that vestibule shields are fitted over the ends of the gangways on the first and last vehicles. He also checks the equipment in his van; this includes an ambulance box, fire-fighting appliances, and rescue tools for use in case of an accident.

As departure time approaches, the platform inspector informs the signalman, usually by means of a push-button which rings a bell in the signal-box, that the train is ready to leave. When the "road" is set and the signals are "pulled off" the inspector blows his whistle. Then when all the doors are closed the guard gives the "right away". The driver opens the regulator valve only slightly so as to prevent slipping, the locomotive shudders, gives a tug at the unwilling train, and the race against time begins.

For the first few piston strokes the fireman opens the cylinder drain-cocks to blow out any water that may have condensed in the cylinders while the engine was standing. This accounts for the familiar hissing sounds and escape of steam from under the buffer beam which is often observed as the locomotive starts.

At the start the driver puts the engine in full forward gear, but as the locomotive gathers speed he "notches up", or shortens the travel of the valves which control the admission and exhaust of steam from the cylinders. The effect of this is to admit steam for a shorter period of the piston stroke, and this allows the steam to expand and to be exhausted at a lower pressure. Thus more work is obtained from a given amount of steam than if the engine was run in full gear all the time. Full gear running would cause the steam to be exhausted at almost the same pressure as it was admitted; and the steam would then carry with it much of its pressure energy up the blastpipe.

Unless something goes wrong a word very seldom passes between driver and fireman; apart from the noise in the cab each is fully occupied. Except for frequent glances at the water- and pressure-gauges, the driver spends almost his whole time watching the signals and looking at the road ahead. The fireman's duties call for both brains and muscle. It is his responsibility to see that the right amount of steam is produced at any time for the varying demands of the locomotive. If too much steam is generated it will be blown away through the safety valve—a very wasteful method of working. If there is too little steam the driver will have to ease the engine, and time will be lost. In a locomotive boiler the margin between these two conditions is very small; in order to obtain the most economical working the boiler pressure should be maintained as near blowing-off point as possible. Fortunately, the fireman is helped in obtaining the various quantities of steam required by the fact that the harder the locomotive is worked, the greater is the draught through the fire caused by the exhaust steam passing out of the blastpipe. The amount of air passing through the fire can also be controlled by opening or closing the dampers under the firebox.

With most kinds of coal the most economical type of fire is one which is thin and slightly saucer-shaped, thicker round the edges than in the centre. By using a thin fire complete combustion of the fuel is obtained. This is most important since incomplete combustion causes waste of heat and it also causes large quantities of soot to be deposited inside the fire-tubes. The soot restricts the area available for the flow of hot gases from the fire, and impedes the flow of heat from the gases in the tubes to the water in the boiler. However, care must be taken to see that there are no holes in the fire through which cold air could be drawn. Jets of cold air produce local cooling and unequal expansion of parts of the firebox. This tends to produce leaks where the tubes join the firebox tube plate and also to produce breaks in the stays between the inner and outer fireboxes. With the exception of some shunting engines almost all locomotive fireboxes are fitted with a brick arch. This is kept at between red and white heat and it therefore ignites any unburnt gases which pass over it.

As steam is generated, so water is used and has to be replaced. It is the fireman's duty to see that this is done, and that the water level is properly maintained. On an average an express passenger locomotive uses approximately 35 hundredweights of coal and 3500 gallons of water per 100 miles. In addition to these duties the fireman is also expected, when not otherwise engaged, to help the driver to keep a good look-out and to observe signals, particularly when they are passing signal-boxes and approaching junctions.

The guard's duties are not so arduous as those of the engine-men. His chief task is to make up a journal in which he notes times of arrival at, and of departure from, stations, and also the times at which the train passes certain points, usually the larger stations and important signal-boxes. The passing times are given every 10 to 25 miles in the working time-table, which is compiled for the use of the railway servants only. This time-table also gives such details as the lines on which they are to run, where they cross from slow to fast lines, and all other necessary details about the running of the train. The guard also enters in his journal the details and explanations of any delays which may occur.

As the end of the journey approaches the fireman closes the dampers and allows the fire to burn low to prevent a waste of steam. When the locomotive is uncoupled from its train it is taken to the engine depot, or "loco" as it is often called, where its supplies of coal and water are replenished. It then moves off to the ashpit, where the ashpan is emptied and the grate is cleaned. Most modern locomotives are now fitted with rocking grates which simplify this operation.

The last duty of the driver before booking off is to make a thorough examination of the engine and to note any defects which require attention. These may include such details as leaking valves and glands, worn brake blocks, and so on.

The water which is fed into boilers contains impurities such as lime which are deposited on boiler tubes and plates as the water is boiled away. This coating of scale is a bad conductor of heat; a deposit one-tenth of an inch thick will cause an increase of coal consumption of about 15 per cent. In bad cases it may cause the overheating and corrosion of the tubes and plates. Another effect often caused by the scale deposit is "priming"—that is, the carrying over of water with the steam into the cylinders. It is therefore important that boilers should be washed out at frequent intervals, usually at about every 800 miles for express passenger locomotives, at every 1000 to 1200 miles for mixed traffic engines, and once a week for goods and shunting engines. The washing out is done by removing the wash-out plugs which are usually found along the sides of the outer firebox wrapper and on the back-head. Steel rods are inserted through the plug-holes and, with the aid of a jet of water delivered at about 50 pounds per square inch, the scale can be removed. It is usual to sweep the tubes and clean the brick arch whenever the boiler is washed out. Tube sweeping is carried out by means of a rod which has a series of holes drilled in it through which are threaded lengths of rope.

Any defects reported by the driver receive the attention of the appropriate fitter or boiler-maker, who, after completing the work, signs the book in which the records are kept to show that the work has been done. The engine is then ready for the attention of the firelighter and for its next turn of duty.

## SOLUTION OF THE BANANA PROBLEM

(Page 10)

Suppose the first man takes $x$ bananas, the second $y$, the third $z$, the fourth $w$, and suppose that in the final share-out each gets $n$ bananas. Then $3x=4y+1$, $3y=4z+1$, $3z=4w+1$, and $3w=4n+1$. These equations are to be solved for $n$, the smallest possible whole number.

If we write all the equations in the form

$$3(x+1)=4(y+1)$$

and multiply them all together we get

$$3^4(x+1)=4^4(n+1).$$

The simplest whole number solution of this is given by $x+1=4^4$ and $n+1=3^4$. Hence $x+1=256$, or $x=255$. The number of bananas in the original heap was therefore $4x+1=1021$.

# Nickel: A Metal of the Past, Present, and Future

E. J. BRADBURY

THE word "nickel" calls to mind perhaps a row of bottles of coloured chemicals in the laboratory, perhaps a silvery-white plating on this or that object, or perhaps it reminds you of America and its coins—but no picture of the great industry created specially to produce this element or of its modern uses. Without nickel the development of many essentials of modern civilization such as radio, gas turbines, and stainless steel would have been slowed down and might never have attained their present importance. Yet we rarely see nickel as itself. What is this useful and beautiful element? Where does it come from? And how do we get it?

It was in 1751, just two hundred years ago, that a Swedish scientist, Cronstedt, examining the strange behaviour of what were believed to be copper ores found in Saxony, isolated a new element and called it Nickel. Even before this time there had been imported into Europe a beautiful white metal, known as "paktong", made in China and known in that country since ancient times. This metal, which was used for boxes and candlesticks, was made in China by adding zinc to what we now know to have been nickel/copper ores. After the discovery of nickel the analysis of the "paktong" revealed its composition and the metal was then made in Europe under the name "German silver". Later still, in 1844, when electroplating was introduced into

England, articles in "German silver" plated with real silver became popular and the alloy became known in this country as nickel silver.

In those early days, though deposits of nickel ore were worked in places as far apart as Norway and New Caledonia, the metal was not used to any very great extent, but when in 1883 the Canadian Pacific Railway was being built across Ontario the blasting revealed a great deposit of ore in the Sudbury district. At first it was mined for copper, but when it was realized how rich were the deposits in nickel men tried to find new uses for it. Today 85 per cent of the nickel used in the world outside Russia comes from this region of Canada, but very great difficulties had to be overcome before in 1890 a successful process for separating the nickel from the copper was developed and the full use of these nickel deposits became possible. Almost at the same time a man called James Riley in Glasgow showed the great improvement in the properties of steel which could be obtained by adding small amounts of nickel. Armament manufacturers and the great navies of the world began to show interest in nickel steel. Immediately the world demand for the element rose and has continued to rise until the present day as fresh uses for it have been discovered. In 1887 the total world production of nickel was only 2,000 tons; in 1949 Canadian production alone was 100,000 tons.

As so much of the world's nickel comes from Canada it is the extraction process used in that country that is of greatest interest. The ore, which is mined both in "open pits" and in deep mines, contains the copper and nickel in the form of sulphides which are dispersed as particles in the rock. The ore is crushed and then

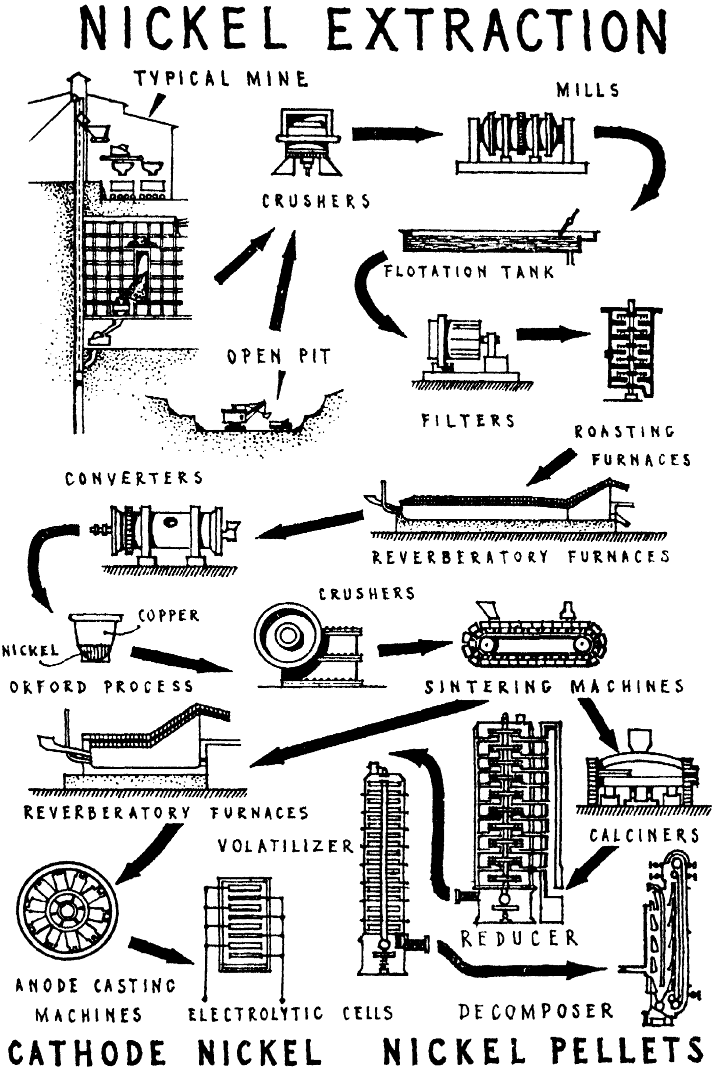


Fig. 1. The extraction of nickel from its ores.

ground in water to a fine sludge so that as many as possible of the particles of sulphide are separated from the rock. This sludge is then passed through a long row of tanks in which the mineral particles are "floated" off, while the rock particles settle on the bottom. Then in other tanks the copper sulphides are "floated" off and the nickel sulphides settle on the bottom. This flotation process depends on the fact that some constituents of an ore, such as the sulphides in this case, are less easily wetted than the rock particles and, therefore, do not readily sink in water; in fact, if there is a constant stream of air bubbles up through the water they are carried to the surface and can be separated from the rock. The concentrate so made which contains the highest proportion of nickel sulphide is then dried and roasted. During this roasting process some of the metal sulphides burn to oxides and sulphur dioxide is given off. The roasted material is then melted in furnaces and transferred to converters. These converters are horizontal cylinders lined with heat-resisting bricks with nozzles at the bottom so that a blast of air can be blown through the molten mass. Intense heat is developed by the burning of sulphur and iron, and most of the remaining rock is removed as molten slag. The material from the converters contains approximately 48 per cent nickel and 27 per cent copper. This is then treated by the "Orford" process by which the metals are again converted into sulphides by heating them with sodium sulphate and coke. When cool the top layer of copper sulphide is neatly broken apart from the bottom layer of nickel sulphide so that at last the two metals are separated. The nickel sulphide is again crushed and ground. The ground mass is leached with hot water to remove the sodium sulphide and is then heated in a current of hot air to produce crude nickel oxide. This nickel oxide is then purified and reduced to pure nickel at refineries either in this country or in Canada.

In the Canadian refineries the nickel oxide is reduced to molten nickel by heating in furnaces with carbon in the form of powdered coal. The molten impure nickel is then cast into anodes for refining in electrolytic cells. The cathodes in these cells are formed of thin nickel sheet; when they are built up to a suitable thickness by the pure nickel which is deposited on them from the anode they are removed from the electrolytic bath and are ready for sale.

In the refining at Clydach in South Wales the nickel oxide is further purified and then reduced to impure nickel by heating with hydrogen at 400° C. Carbon monoxide at 50° C. is then passed over the impure nickel, when the nickel forms nickel carbonyl, $Ni(CO)_4$, which is a gas. This surprising reaction, discovered by Mond in 1890, is used to make the final separation of nickel from its impurities, which contain valuable metals like platinum and rhodium which are subsequently purified and form a valuable by-product. The gaseous nickel carbonyl is passed to decomposers, which are boxes one on top of the other, each box filled with nickel pellets and continually shaken. The decomposers are heated to 180° C. and at this temperature the nickel carbonyl decomposes to nickel which is deposited round the nickel pellets, and to carbon monoxide which is used again. These pellets are the form in which the nickel is sold.

Most people associate nickel with plating, and indeed until comparatively recent years nickel plating was a common means of adding a durable and pleasing finish to household and decorative ware made in brass, steel, and other cheap materials, so that the silvery-white colour of nickel became quite well-known. Though nickel plating is still the second largest field of use for the metal it is now more used as an undercoat to chromium plating. The chromium provides the hard durable finish which keeps its appearance and the nickel provides the corrosion-resisting undercoat.

This property of nickel, its resistance to corrosion, has also led to its use in solid form. Nickel resists corrosion by caustic soda, dry chlorine, and hydrochloric acid and is, therefore, widely used in the chemical industry in the construction of chemical plant where steel and other metals would not last long. Nickel coins, the first of which were struck in Switzerland in 1881, are becoming increasingly popular, and now India, Israel, Spain, and Canada all use pure nickel coins.

The physical properties of nickel are used in many special instruments. Its high temperature coefficient of electrical resistance is used in electrical resistance thermometers. The magnetic properties are employed in the magneto-striction of nickel—that is, the property of changing its dimensions in a changing magnetic field. A piece of nickel sends out sound waves when it is placed in an alternating field of suitable frequency. This property is used in depth-sounding equipment, and the application is illustrated in Fig. 2. The pack of thin nickel discs can be seen with the coil through which an alternating current is passed. When the nickel pack is mounted on the hull of the ship the change in dimensions of the pack induces sound vibrations in the hull.

The sound waves travel to the bottom of the sea, and are reflected back from there; they are picked up again by a receiver placed also in the ship's hull. The time taken between the beginning of the sound pulse by the vibrating pack and the return of the reflected sound is a measure of the depth of the water and can be plotted, as shown in Fig. 3.

Another little-known application of pure nickel is in the construction of some of the metal components in radio valves. The properties which are required of a metal for the construction of electronic components like grids, anodes, and cathodes are too complex to describe in detail, but nickel is used for these in most radio valves. An illustration of the structure of the metal components of a cathode-ray tube is given on page 13.

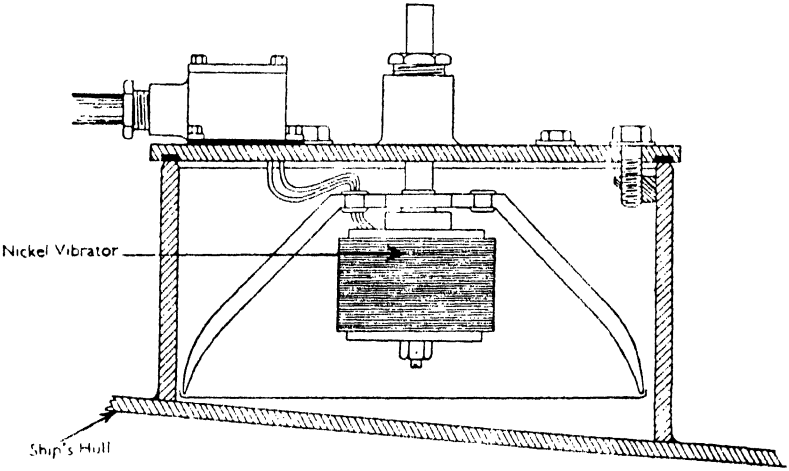


Fig. 2. Diagram showing construction of magneto-striction oscillator for echo sounding.
*Courtesy of Messrs. Kelvin & Hughes.*

It is not, however, as a pure metal that nickel is of greatest importance, but as an alloying element—i.e.

as an addition to other elements to modify their properties. Over 40 per cent of the nickel used today is used in the manufacture of special steels. As we mentioned earlier, Riley found that small additions of nickel, generally below 5 per cent, greatly improved the strength, toughness, and wear-resistance of steel, and this was the first large-scale application of nickel.

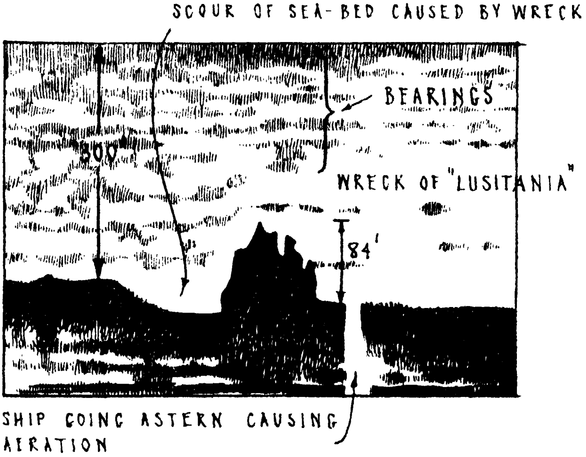


Fig. 3. Depth-sounding echo from sunken ship (the *Lusitania*). *Courtesy of Messrs. Kelvin & Hughes.*

Today many such nickel steels are made in which nickel together with other elements such as chromium, vanadium, molybdenum is used. Many things that have to stand hard wear—gear wheels, drive shafts, tools, armour plate—are made in nickel alloy steels.

By far the largest single application of pure nickel is in the manufacture of "stainless steels". Mild steel or the low alloy steels described above are not corrosion resistant, and the demand for steels which would resist corrosion was first met by so-called stainless steels containing 12–20 per cent. of chromium. Further improvements, which combine corrosion resistance with strength and toughness, are obtained by adding nickel up to 2 per cent. Increase in the nickel content to 8 per cent results in "austenitic" corrosion-resisting steels, which include the widely known "18/8". This kind of steel has outstanding corrosion resistance, yet it is easy to work and is used today in many industries to resist the corrosive attack of many substances, particularly oxidizing substances such as nitric acid.

These "stainless steels", because of their pleasing appearance when polished and their resistance to tarnishing in the air, are also used in many architectural applications.

There are some alloys composed of nickel and chromium with, sometimes, iron in a smaller proportion than is present in the alloy steels just described; these alloys show remarkable resistance to the effects of heat. They resist scaling by oxidation because they have a tenacious skin of oxide which forms on their surface and prevents access of the oxygen to a fresh metallic surface beneath the scale.

The alloys vary in composition from those containing 25 per cent nickel, 20 per cent chromium, 55 per cent iron, to those containing 80 per cent nickel, 20 per cent chromium, and no iron, and the oxidation resistance increases as the iron content diminishes, the 80/20 nickel/chromium alloy being resistant to scaling at temperatures up to 1250° C. Metals in general lose strength and become softer as their temperature rises. These alloys retain a reasonable degree of strength at high temperatures, but by adding small percentages of other elements the alloys can be made to retain much of the strength they show at room temperature, even when they are heated to 850° C. This property is of very great importance today in gas turbine design. In such turbines hot gases at temperatures of up to 850° C. flow through the fixed blades of the turbine and then through the blades attached to the turbine disc which is free to rotate, so that the blades become "red hot". When the turbine is developing power the blades rotate at very high speed and the centrifugal acceleration sets up severe stresses in them. If alloys of the type described above were not available only very low temperatures would be possible in the turbines and then their efficiency would be very poor. In fact, the 80 per cent nickel, 20 per cent chromium alloy is the base material of the alloys used for all moving blades in all aircraft gas turbines made in this country. These nickel/chromium alloys, with or without iron, are also used for the flame tubes of the turbines in which the fuel is actually burnt.

One of the most interesting series of alloys is that made by the alloying of iron with nickel. The alloys are of interest because of the very wide range of physical properties which is made available through them. Some have very low thermal expansion; others make springs little affected by rise of temperature; and still others have unusual magnetic properties.

Modifications of the simple nickel/iron composition by the addition of cobalt and chromium are made, and many alloys have been developed for special purposes, but the basic properties are those illustrated in the three curves shown.

Alloys with controlled expansion properties are used in many applications. When metals are to be sealed to glass the glass will fracture if the metal does not have an equal expansion coefficient, and the different expansion properties of various kinds of glass can all be met by choosing a suitable nickel/iron alloy. In the thermostats for controlling temperatures use is made of the difference in expansion with rise and fall in temperature of the nickel/iron and, say, brass; the nickel/iron alloy containing approximately 36 per cent nickel has a practically negligible expansion coefficient and brass has a fairly high coefficient. The same property is used in the construction of bimetallic strip in temperature controllers (Fig. 4), in which a layer of the nickel/iron alloy is bonded to a layer of brass or other alloy of high temperature coefficient. When the temperature of such strip is raised the strip becomes curved with the nickel/iron alloy on the inside. This curvature, which is proportional to the temperature of the strip, disappears when the strip is cooled and can be used to control electric switches.

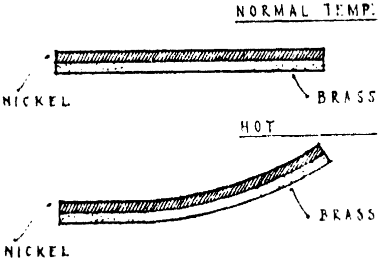


Fig. 4. A bimetallic strip.

The magnetic properties of these alloys are equally important and useful. An increase of the nickel content decreases the magnetic properties until, with 28–30 per cent nickel, the alloy is non-magnetic, and alloys of that composition are used to reduce energy losses in electric generating plant and to eliminate errors in instruments.

Magnetic permeability begins to increase with further addition of nickel and alloys with 78·5 per cent nickel have very high permeabilities. Such alloys are particularly useful when low magnetising currents are employed, as in telephone instruments where the alloy is used as diaphragms, and for screening electrical equipment such as cathode-ray tubes from electrical interference.

The alloys of constant or controlled elastic modulus are used in scientific instruments where springs are required to exert a constant effort despite changes in temperature, and alloys of this type are used for watch springs and pneumatic bellows in meteorological instruments.

Even that despised material, cast iron, can be made more interesting by adding nickel to it. It can be made to resist hard wear or corrosion, or to be tough and strong according to the proportion of nickel added. These modified cast irons are used for the wearing parts of rock crushers, for machinery handling caustic alkalis, and in the manufacture of engine cylinder blocks and crankshafts.

So diverse are the alloys in which nickel plays a part that many of them can only be mentioned. Many of the light alloys used in aircraft, motor-buses, etc., contain nickel. The millions of springs in telephone exchanges and the spoons and forks marked "E.P.N.S." are made from nickel silver, the alloy developed from the "paktong" of China and which contains about 18 per cent nickel. Alloys of nickel and copper are used for the thousands of tubes in the steam condensers in power-stations, naval ships, and many ocean liners such as the *Queen Elizabeth* and *Queen Mary*. There are, in fact, few pieces of equipment which do not use nickel in some form or other. It is rarely as obvious as when it is used in coinage, since it is usually employed in alloys or in the manufacture of articles in which its presence is not apparent.

Progress in the development of nickel uses has by no means ceased, and new applications for nickel are constantly being found. New alloys are being experimented with and the increasing demands made by modern industry for materials to resist still higher temperatures and still harder wear, or with new special properties, are a constant inspiration to explore further the properties of nickel and its alloys.

## A PROBLEM ON RANDOM NUMBERS

If you stand by a busy road and note the last digits of the registration numbers of cars that pass by, you will get a series of "random numbers". Suppose the series began 7, 6, 0, 3, 3, 4, 7, 9, 7, 2, 7, 7, . . . and you counted the number of cars until the first digit, 7, recurred, you would get "scores" of 6, 2, 2, 1, . . . (You *might* get a score of 100!) What is the most probable score?

(Answer on page 96.)

# The Beasts of the Deep

### JOHN UNDERWOOD

I GAZED down at Sedgcombe's craft from the jetty.

"Whatever's it supposed to be," I asked him, "a torpedo or something?"

"It's the Sedgcombe atomic underwater craft," he answered proudly.

"I can see that it might be underwater," I said, "but what about atomic?"

"It's propelled by an atomic engine, and depth-pressurized by atomic means. There's a great deal of thought and work gone into it."

"That I can certainly believe," I said, "and what about money? Where has that all come from?"

"Well, most of that has come from me, my relations—or those who are well enough disposed towards me—and a little loan I floated. But I can tell you, Underwood, that if we don't get down to those galleons I shall be in a bad way. I'm gambling on finding some treasure down there, to pay me back for all the time and money that's gone into it."

"I hope you succeed. But what are you doing for crew? How many people does it hold?"

"It holds two. And I can't conceal from you any longer that the main reason I got you to come down here was to ask you if you'd come down with me."

"What, in an atomic submarine? Do you think I'm mad?"

"No, but I know you're nearly broke. A journey like this, and even if we didn't find any treasure we'd come back famous."

If we came back at all. But I thought over what Sedgcombe had said. It was quite true that I was broke, or very nearly, and a man with one leg lost in the war can't always get the sort of employment he wants. This looked like a chance, at least. One look at Sedgcombe's eager face decided me.

"Righto, Bill," I said, "I'll come."

"That's grand, John. We'll be able to start next week, but first I'll have to get you used to the controls, so that we can both work the craft in an emergency."

We spent the week examining Bill's brainchild, and I had to keep hard at it to understand everything he told me. There were a number of startling features. Bill had discovered a radio-ray absorber, twenty times lighter than lead, that could absorb the rays given off in the atomic breakdown without being nearly so thick or heavy as lead, and the cooling was done by the sea water, so the only sufferers would be fishes who ventured too close. The heat generated by the atomic breakdown was used to drive an unorthodox-looking propeller, more like a turbine rotor than anything else. The steering and elevating and lowering gear were normal, but Bill had substituted a pressure-equalizer in place of the normal thick skin. By building up the pressure between three walls to different intensities, and by pressurizing the interior at the same time, he had made each of the three skins light without losing much strength. In the front of the craft was the plastic nose, through which we could see and photograph anything we saw. Mounted on the front were a searchlight, a pair of grabbers, and an underwater burner instrument for getting through any sort of metal plate we might find down under. He had also devised some special self-sealing pockets on the outside of the craft, so that any valuables we found could be put in them and transported to the surface. The grabbers were mounted so that they could swivel round and deposit anything in these pockets. Inside space was cut to the minimum. We could only just stand, and that by bending our necks. For normal travelling we had a couple of seats, and the controls were mounted on a board so we could see them and look out of the plastic nose at the same time.

At the end of the week Bill said that we were ready to start practice dives and get ourselves acclimatized to pressure. We had to go out into the bay, not as far as the place where the galleons were supposed to have sunk, to where we could dive deep enough to get accustomed to the pressure. It was bad at first, but I got used to it and even found that I liked the feeling. On the way back we picked barnacles off the supports of the pier to make sure the grabbers worked all right, until we got tired of emptying the bins every time we came up.

Bill had managed it so that there was some publicity but not so much that we were bothered. Nobody really believed we were going very far down with our craft, and Bill told me how he had fixed it. He had made friends with the editor of the local paper, and when we actually went down, the editor was going to write up the story of what we were doing. Bill had said that with his special air purifiers we could stay down for a week at least, and so we would create quite a stir by coming up after a week and everybody would probably be waiting for us. That was what he hoped, anyway, because if we found no treasure the only hope for us was to become famous although unsuccessful.

A handful of people came to see us set

After two weeks of practice Bill said we were ready to go. The night before we went we had dinner with Bill's editor friend, and drank to good fortune. The day we had chosen turned out to be a lovely day, although, as Bill said, it wouldn't make much difference after the first few feet down. A handful of people came to watch us set off, and we stepped down into our seats once more, closed the three watertight doors, one for each skin, started the engine, and set off, down into the unknown.

It was familiar enough for a start, the increasing pressure, the light growing fainter, and the complete stillness of the water. Now and then we saw fishes swimming towards us, but they sheered off rapidly when they felt the heat we gave out, and when we switched the searchlight on. We were finding our way towards the galleons by a simple bearing and distance method. The distance we measured by an instrument working off a small propeller below the hull. We had to go twenty miles NNE from our port, and at that point Bill reckoned the bottom was 3000 feet down.

"But we'll be quite near the edge of the Shelf there," he said, "and we may have to go down to about 6000 feet. It depends where they sank, and nobody knows that for sure."

We were going to take the descent pretty easily. Even though we had got acclimatized to pressure, it was always more comfortable to take the descents easily and we had plenty of time.

As we descended the surrounding water became blacker and blacker. We had the searchlight switched on permanently now and Bill used the rheostat controlling the brightness to make sure it worked. The beam stabbed the darkness and picked out a massive shape that turned and moved rapidly away.

"Wouldn't want to get caught by one of those," said

Bill. "You can't see what size mouths they've got but I'd be willing to bet it isn't very small. Our only chance with them is to turn round and give them a blast of the exhaust. It'd be interesting to see how long it takes for an atomic blast to kill a whale."

The creatures that we saw now appeared to be all eyes.

"They have to have enormous eyes so that they can see anything at all in this blackness," said Bill. "It looks as though all their food goes towards making eyes and leaves none for the body."

The bottom might be somewhere near now. We could see the long, trailing, whitish plant fronds coming up from the bottom. Unless they were very long the sea bed couldn't be far away. We slowed down our speed of descent, and began to circle round. The vegetation was thicker now, and we didn't want to get caught up in it.

"If the whole of the sea bed is covered with this stuff we'll never find anything," said Bill, "and what's more we'll probably get caught up."

"Why don't we go down backwards," I said, "then we can blast our way through with the exhaust?"

"No, that'll be no good, we shall probably get stuck and not be able to get out. We shan't see where we're going, and we can always blast our way out backwards if necessary."

We glided through the long waving fronds, weaving in and out, up and down, playing hide and seek with the fishes. Suddenly we came to what seemed to be an open space. We were still above the sea bed, and we struck downwards. It was only fifty feet below us, so we couldn't have missed anything in the forest. Now we were able to move over the sea bed and cover the ground much more quickly. We had moved backwards and forwards, covering as much ground as we could, and keeping a check on all our movements with the chart for about four hours.

"We should be near the Shelf," said Bill. "If we get much nearer we can only assume that the galleons have sunk beyond the Shelf. That'll mean diving down again."

Suddenly I saw a shape ahead.

"What's that, Bill? Can you see it?"

"You've got it, John. We'll go slow, and take a look round it."

It was an old hull, most of the side timbers gone, but the masts were still there, and it was recognizably a ship. The bows were deep in the sea bed, and we circled round to the stern.

"There must have been a name somewhere here," said Bill. "Can you see anything?"

"What's that carving there? See that shield on the back? Get a bit closer and I'll read it."

The name became recognizable as I got closer. *Santa Theresa, Cadiz* was the name.

"This is one of them, Bill," I cried. "There's our fortune."

"Not so quick, John. We've got to find it first."

We moved round the hulk, looking for a suitable way in. Our difficulty was that we had to move in bodily, the whole craft or nothing at all. Even if we'd had diving suits, the pressure at this depth would have crushed the life out of us.

"We've got to work out where the treasure would have been, and go straight for it," said Bill. "We should be able to see where any likely strong-room is.

I don't suppose they had any safes in those days, so we'll have to look for some heavy timbers."

In the stern of the ship was a place where the captain's quarters had clearly been. This cabin was comparatively large, and we could see where the old portholes had been in the poop. Underneath this was a small room, or more accurately, a cupboard. We could see this much through the side, but we couldn't see how deep it was.

"We'll take a chance on it, John. The captain would be bound to have his eye on any valuables he was carrying, and what better place could he have chosen than beneath his own cabin floor? We'll start boring through to get at that. The best way will be in from the stern."

The propeller engaged once more, and we went round to the stern. We had to move the grabbers away from the front and get the burner in position. This was like an underwater oxy-acetylene burner, and in the tests we had made it had worked well cutting through metal. We hadn't tried it on wood, but we reckoned it would cut through like a knife through butter. We were right, too. We only had to burn each side of the square we were taking out for about two minutes and the job was done. We put back the grabbers, and gave the bottom of the square a biff with them. The top came out a little way, and we were able to get the grabbers over the top and lower it out. Excitedly we turned the searchlight full on and looked in the recess. "Doesn't seem to be much there," said Bill, with disappointment in his voice.

"Look up at the top there, Bill. Isn't that trap-door off?"

We edged a little closer and turned the searchlight upwards. We could see that there had been a trapdoor from the floor of the captain's cabin down into the recess, and it was no longer there.

"Someone must have known about it, and taken whatever there was away. We shan't find much here," said Bill. "The only thing we can do is to have a go at the other ships."

We slowly withdrew from the ship and started cruising around once more. We had only gone about a hundred yards from the *Santa Theresa* when the sea bed suddenly disappeared, and the whole sea beneath us turned darker.

"The Shelf!" said Bill. "If there are any more ships they must be down below there. We shall have to go down and see. Ready to dive another 2000 feet, John?"

"I'm ready enough," I said. "What about the craft? How are we doing for pressure?"

"That's all right," said Bill, "we've only got to about a third of maximum safe pressure so far. Another 2000 feet shouldn't bother us much."

"Right, then, down we go."

We started to dive down, and kept close to the cliff face. The Shelf was just like a huge underwater cliff, and we could see the rocky formations as we went past. To keep ourselves more or less vertically in line with the *Santa Theresa*, we zigzagged down and kept close to the cliff as we dived. Bill kept looking at the cliff formation and muttered to himself.

"What's the matter with you, Bill?" I asked. "What's so odd about these rocks?"

"They look volcanic to me," Bill replied. "I suppose this shelf could have been due to volcanic movement at some time, but there's no knowing what we'll find as we get lower. Still, we may as well press on now."

Down and down we went, but here there were few animals, and practically no vegetation. The animals we saw were all characterized by their huge eyes and a ghastly slug-like whiteness about their bodies—such as they were. There was nothing growing on the cliff face, and when we turned the searchlight on to it we could see the basalt rock so typical in volcanic formations, black and twisted into curious shapes. The pressure was now mounting rapidly inside the cabin. The depth meter measured 5000 feet, and I began to feel the oppression due to the great depth. I wondered whether we could stand another 1000 feet.

Bill must have read my thoughts, because he said suddenly. "We can go down another thousand feet all right, but I wouldn't want to go much further. I should say 6500 feet is the absolute limit."

But the bottom came before we had gone much further. At 5500 feet we could see a difference in colour where the searchlight was pointing which we knew could only be due to the sea bed. And so it was. We circled down slowly, and saw the difference immediately. Here the sea bed was rocky and black, whereas up on top of the Shelf it had been sandy and covered with vegetation in places. The rocks were in some places jagged, and had they been nearer the surface would have been most unpleasant for any sort of ship. But here in the timeless stillness a ship could settle down in its grave and never be disturbed until it rotted away on its own. We cruised round keeping close to the Shelf.

"If they were all sunk together they must be quite *close to the base of the Shelf," said Bill. "We'll soon find them."*

The searchlight suddenly picked out some old timbers.

"Look, Bill," I shouted, "those aren't rocks."

We moved closer to the timbers. It was still just possible to see that they had once formed a ship. They had all fallen apart, and the deck had fallen down until it was nearly resting on the keel. We looked at each other in dismay.

"If there's anything there we'd be bound to see it as we go round," I said, "and we haven't seen anything at all yet."

"Mustn't be downhearted yet," said Bill. "It doesn't take a lot of gold to make us very rich, and there's plenty of room here."

But we went from ship to ship, and still saw nothing at all. We were sailing round the last ship when I suddenly noticed a curious light effect.

"Move the searchlight a bit, Bill," I said. "See if that light moves."

Bill moved the searchlight round, but this light, or more accurately phosphorescence, remained exactly where it had been.

"Whatever can it be?" I asked Bill.

"We'd better go and have a look. There's not much hope of picking up a fortune here, and we may as well try anything that promises to be different."

So we set out towards the light, still keeping to the edge of the Shelf. As we got nearer to the source of the light, the light became stronger and stronger, and finally we were able to turn the searchlight off and still see our way. The quality of the light was curious, as if a hard fluorescent light were shining through a denser medium. And then we came to the source. Hollowed out in the cliff was an enormous cave, whose entrance only we could see from where we were. The archway that formed the entrance to the cave towered up into the wall of the Shelf, so high that we could not distinguish the top through the intervening water. The light seemed to come from the top and sides of the cave, and the cave was so long that we could not see to the back.

"Are we going in, Bill?" I asked.

"We certainly are," Bill replied. "We know there's no treasure out there by the ships, so we'll just see what we can get here in the way of photographs. They may not be worth as much as some gold would have been, but they'll still bring us in a pretty penny."

So we started off into the eerie atmosphere of the cave. We could see now that the light was not continuous. There was a sort of flickering from above, as if there were intermittent discharges of electricity, although from outside the light appeared to come from a steady source. We had gone a hundred yards or so towards the end of the cave, when Bill gave a sudden grunt, and turned towards the side of the cave.

"What's over there, Bill?" I asked.

"Some funny-looking stones," he replied. "Can't you see them over there?"

I looked where he pointed, and saw some nearly square stones, about the size of a half brick.

"We'll see what they are when we get them up," said Bill. "If we just take a couple, they may be interesting."

We got hold of two of these with the grabbers, and put them one at a time into the pockets we had designed specially for our treasure.

"Got something in the pockets, anyway," said Bill, "even if they only turn out to be a lot of stones."

We were still moving towards the far end of the cave, and we could see now that there was some sort of concentration of light at the back there. Suddenly I saw some odd shapes moving about, shapes that I had never dreamed of seeing anywhere on this world, even a mile under the sea. They had one enormous eye perched on a stalk which sprouted from the top of what could only be called the head. Coming out from above the body, or what lay behind the head, were four huge tentacles. These were in two sets, one of which came out above the eye and one below the eye. All four were ghastly to look at; the top two were each armed with an enormous claw, and the bottom with a gigantic sucker.

"Can you see what I see, Bill?" I almost shrieked. "What in goodness' name are they?"

Bill had turned white and stared out of the plastic nose in horror.

"If they see us," he said, "I don't know what we can do. We'd better turn round and get out quickly."

But he had spoken too late. Although the beasts were still some way from us, their sight must have been very acute. (We found later that they had no hearing, so they could not have heard us coming.) Several of them suddenly turned, and with a whirling motion of all four tentacles they propelled themselves towards us. I was too frightened then to do any observing of the creatures' way of moving, but I saw later that they had a tail-like projection that served as a rudder. They came towards us at an unbelievable speed, and flight was out of the question. When they got close to us, we could see that each one was about half the size of our machine. The first one to get up to us put a tentacle against the side of the submarine, and swivelled its eye round to have a look inside. His eye at close quarters was so huge that it did not seem to us that anything was looking at us. Without the surrounding of a face, and without any expressive movements, it was difficult to believe that anyone could say that the "eye was the mirror of the soul". As if they had souls, anyway! But they must have been able to see with those things. The first one to look at us tweaked a companion with his claw, and suddenly we found the whole of our plastic window covered with eyes—huge, globular, disembodied eyes. What we must have looked like as we tried to get further back into the shell of the machine I didn't like to think. Then suddenly they all moved away from the window, and we saw them let their eyes rejoin their bodies.

Bill looked at me with a white face and said, "Perhaps they're going away." But there was despair in his voice as if he knew quite well that there was really no hope of such a thing happening. Then there was a gentle thud on the side of the submarine.

"Let's hope they don't try to use their claws on the sides," said Bill. "I doubt whether they'd do much, but it'd be jolly unpleasant to hear it from inside. Like being a sardine while the can's being opened."

They were not touching us with their claws, however. A few of them had put their suckers on the side of the submarine, and we felt ourselves being moved gradually forward. We could imagine what it looked like outside—each of the beasts with one sucker attached to us,

"Let's hope they don't try to use their claws on the sides," said Bill.

and the other three tentacles whirling round like a twelve-bladed underwater helicopter. I expect they found it difficult to get used to using only three at first, but gradually we increased speed, and were drawn along towards the end of the cave where the brightest light was. As we went along so the numbers of the beasts surrounding us increased, and we had quite an escort by the time we came to the end of the cave.

We could not make out what their purpose was, but we could see now that the light was surrounding some square, curiously opalescent object at the end of the cave. It was a large block of some sort of metal, and it stood on a flat but irregularly shaped rock, like a paving stone. We were brought up to this object, so that we could see it sitting some twenty feet in front of us. The beasts were behind us now, and we couldn't see what they were doing. Then two larger beasts came swimming round towards us from either side. They picked us up and moved us round so that we were lying with our side parallel to the flat-faced rock. By peering round the corner of the plastic nose we could see the other beasts were all lined up, as if they were about to watch something.

"They look as though they're going to watch a play," said Bill with a ghastly attempt at humour.

"Perhaps they are," I replied, "but I'm afraid we're going to be taking some sort of part in this play; and not a very pleasant one either."

Then we suddenly had an insight into what they were going to do with us. The two beasts removed the large metallic block from the flat rock, and took it a little way away. Then they moved us on to the flat rock, this time with the nose facing out towards the crowd of beasts. I saw at once what they were up to.

"Bill!" I shrieked, "they're going to smash us to pieces with that stone thing as we sit on this rock."

"Not as long as we can move they're not," said Bill.

We could see the two beasts lift the stone up. Perhaps they would drop it, or perhaps they would bring it down like a hammer. We didn't wait to see, but as they took the rock up to a position above us, we gave the submarine full throttle, and shot upwards and outwards, twisting round the two beasts holding the rock and heading towards the top of the cave. Immediately the two large beasts followed us. The one with the rock still held in its claws was having some difficulty in rising up while carrying such a weight. But the other one gained on us rapidly, and we realized we would have to fight.

"You steer," said Bill, "and I'll work the burner and the grabbers. If the worst comes to the worst we can at least turn round and see how it likes the exhaust."

The beast was close up to us now, and managed to catch on to us with one of its suckers. Then it moved one of its claws round and grasped the end of the nose. It was nasty to hear the scraping noise the claw made as it grated across the plastic. But it was perfectly smooth, and it was clear that the beast could make no impression that way. It tried once more, but this time Bill was ready for it. As the claw was slipping off the end of the nose, Bill grabbed its claw in our mechanical grabber. Immediately the beast tried to shake free, and darted upwards, dragging us with it. Bill kept his head, and held on with the grabbers. At first the burner wouldn't work, but suddenly it caught and the flame darted out. The beast thrashed around violently, but relentlessly Bill started to burn its claw off. We could almost feel the beast's agony, but Bill went on burning till he was through. Then the beast sank slowly down, and the claw dropped off the nose.

This fight had lasted long enough for the second large beast to get up to us. It still held the block of metal, and one hit from this might do us a lot of damage. Our only chance was to keep away until there was a chance to make it drop the block, then we might be able to fight it as we had the other. Suddenly I had a plan. I drove straight for the beast, and when we were nearly colliding with it, turned upwards and then outwards so we were momentarily upside down. We felt a bump on the side as the beast brought the block down on us, but the blow was not as bad as we had expected. The beast must have taken the full blast of our exhaust right on its most sensitive portion, the eye. As we turned back again we saw that it had. It was thrashing round wildly, but it was obvious that it could see nothing at all. It thrashed back towards the end of the cave, and we immediately turned towards the open sea bed.

"Watch the others," said Bill, "and take a look at that pressure-gauge. What's wrong with it?"

This gauge gave the pressure between the outer and middle skins. It was registering up to the danger mark.

"He must have holed us, Bill," I said. "We shall have to get up as soon as possible."

"If these others don't get in our way we shall be all right."

The others had seen what had happened between us and the two large beasts, and we saw them all rise from the cave bed and start towards the cave entrance. They were trying to cut us off between them and the top of the cave.

"We'll have to risk it," said Bill. "Push her along as hard as she'll go, and let's hope she'll go fast enough."

It was a close thing to the end of the cave. The pressure-gauge was mounting, and the beasts were getting nearer, and with about twenty yards to spare we got to the end of the cave.

"They won't follow us upwards," said Bill. "Don't worry about that."

They didn't follow, and drifted downwards as we shot rapidly upwards. After a thousand feet the pressure was all right, although we were beginning to feel the strain. It took a lot of willpower to go slowly up to the surface, but we managed to, and eventually we reached the top.

The journey to harbour was quickly made, and there we were again entering the little port. We made no fuss about an entry, but as soon as we came in the people began to gather. We were, we discovered, world-famous overnight. Bill's editor friend had fixed that for us by some excitingly worded articles he had sent to the main daily newspapers. But we discovered that we had no need of publicity to make us rich. The stones we had picked up in the cave were solid platinum, worth about £20,000 each. Bill and I both agreed, however, that we wouldn't risk another encounter with the beasts, however many more stones there might be down there!

## ANSWER TO THE PROBLEM ON RANDOM NUMBERS (p. 77)

It is assumed that if you counted thousands of cars there would be equal numbers of 0's, 1's, 2's . . . and 9's. The probability of a score 1 is therefore $\frac{1}{10}$, of a score 2 is $\frac{9}{10} \times \frac{1}{10}$, of a score 3 is $(\frac{9}{10})^2 \times \frac{1}{10}$, and so on. The *most probable* score is therefore 1, but notice that the *average* score will be 10.

*INSTRUMENTS OF SCIENCE I*

# The Wilson Cloud Chamber

R. H. CAMPBELL

THE idea of seeing atoms in a fog sounds silly; in fact the idea of seeing atoms at all is strange when we remember that the smallest drop of water visible to the human eye on a misty window contains atoms numbering 10 followed by about 12 noughts. And it is no good using the best microscope we have because the light waves themselves are much bigger than the atoms we are trying to see. Yet in spite of this it is perfectly true that the nearest we can get to seeing atoms is in a fog produced artificially in the apparatus called the Wilson Cloud Chamber. How can this be done? First let us see what makes a fog occur.

Air, or any other gas, can always contain a certain amount of water vapour, even though its temperature is not above the boiling point of water—steam comes off the surface of water before it boils. If there is a lot of water vapour in the atmosphere we say it is "humid", but there is a limit to the maximum possible amount of water vapour the air can contain. If the air contains this maximum amount we say it is "saturated". This maximum amount of vapour that the air can hold depends on the temperature of the air; the higher the temperature the more water vapour can the air hold. The air in contact with any water will always be saturated. If the temperature now falls the air will contain more water vapour than it should, and it will have to lose some. If the fall in temperature is large water will drop out of the air as rain, but if there is only moderate cooling then only a little of the water will come out of the damp saturated air, and it will come out as a mist or cloud.

The Cambridge physicist C. T. R. Wilson was studying the formation of fogs in this manner in 1898 when he started on a train of ideas and discoveries which led ultimately to the perfection of the Wilson Cloud Chamber as a marvellous aid to nuclear physics. This first fog-making apparatus was, however, very simple—just two glass jars connected by a pipe with a tap in it. One jar contained moist (saturated) air and the other was pumped empty of air. When the tap was opened the air expanded quickly into the empty jar. When gases expand very quickly they cool. You may have noticed that the air rushing out of a bicycle tyre when it is suddenly let down is quite cold. As a result of such cooling, clouds form in the moist air since only a smaller amount of water vapour can be held by the air at the lower temperature. Wilson found that with ordinary air fogs could be produced even by small expansions, that is, by a small drop in temperature. However, with very clean air Wilson found that he got fogs only if he cooled the gas a lot by making a big expansion. This is because the small drops of water in a fog form on the smoke or dust particles in ordinary air. In clean air the drops cannot form and we say that the air is "supersaturated", that is, the air is holding more water vapour than it normally would.

Fogs cannot form unless the cooling is very marked. This is because small drops tend to evaporate again more easily than the large drops. It is therefore very difficult for any drops to begin to form at all unless they form immediately into large drops, as they would if the cooling were pronounced. The dust particles in ordinary air act as a very convenient beginning for the drops, because they are already of sufficient size for the drops formed on them to avoid re-evaporation. This explains why fogs and mists are much more common and more persistent near large manufacturing towns, where there is a lot of smoke and dust, rather than in the clear air of the countryside.

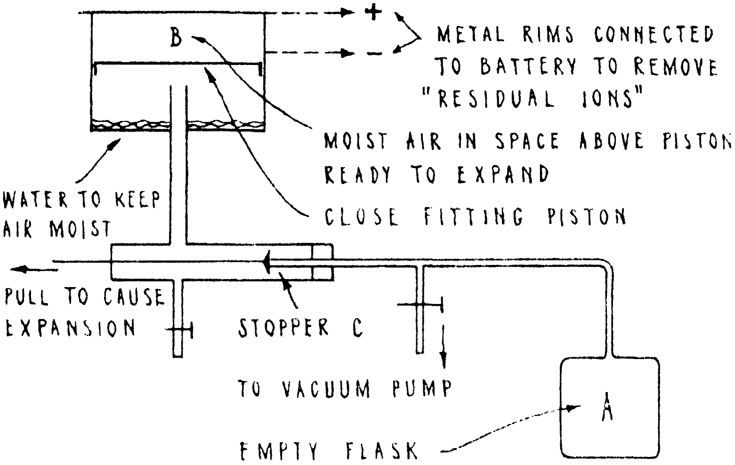

+
B
–
METAL RIMS CONNECTED TO BATTERY TO REMOVE "RESIDUAL IONS"
MOIST AIR IN SPACE ABOVE PISTON READY TO EXPAND
WATER TO KEEP AIR MOIST
CLOSE FITTING PISTON
PULL TO CAUSE EXPANSION
STOPPER C
TO VACUUM PUMP
A
EMPTY FLASK

Fig. 1. Early form of Cloud Chamber.

One of Wilson's cloud chambers, designed in 1912, is shown in Fig. 1. The moist air is contained in a glass-topped cylinder B by a close-fitting piston. The air in flask A is pumped out by a vacuum pump, while the stopper C is kept closed. When you want to operate the apparatus this stopper is pulled out so that the air beneath the piston rushes out into A. As there is nothing to hold up the piston it falls, and thus allows the damp air to expand and cool, and form a cloud.

Wilson soon discovered that even if he used very clean air he still occasionally got clouds with only a moderate amount of cooling when there was some radio-active substance or a source of the then recently discovered X-rays near his cloud chamber. He soon showed that this was because the air in his chamber was being "ionized" by the radio-activity or by the X-rays.

Let us see what happens when air is ionized. The atoms of the various gases that make up air are all built of a heavy positive nucleus surrounded by very light negative electrons. The amount of positive charge on the nucleus is exactly balanced by the number of negative electrons surrounding it, so that the atom as a whole is electrically neutral. Although it takes quite a hard knock by a particle from one of the powerful "atom-smashing" machines (more correctly "nucleus-smashing") to break off a bit of the nucleus, the negative electrons are held to the atom only by the electrostatic attraction of opposite charges between negative electron and positive nucleus. It is therefore much easier to remove an electron from the atom, either by strong electro-magnetic radiation (X-rays) or by collision with another atomic particle like those shot out by radio-active substances. Before impact the atom was neutral, but after it has lost a negative electron it becomes a positively charged "ion". The electron it has lost is a negative ion; it is free to move until it joins another positive ion to form a neutral atom. When an atom is split in this way into two ions, positive and negative, we say it is ionized.

If ions of this type are present in moist air their effect is twofold. First, they attract many more normal atoms to themselves, with the result that a cluster of atoms is formed. Secondly, the charge on the ion reduces the tendency of small drops to evaporate. All this means that the charged ions in moist cooled air act as suitable nuclei, like dust and smoke, on which fog and clouds can form.

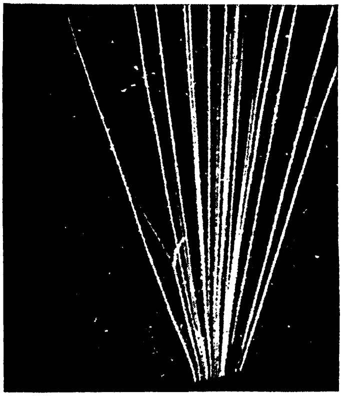
To make this clear we will follow up what happens when an alpha-particle passes through a cloud chamber immediately after expansion has taken place, and when the moist air has been cooled so that it is ready to form clouds. An alpha-particle is a fragment shot out of the nucleus of a radio-active atom. It is about four times as heavy as a hydrogen atom, it has a double positive charge, and it will travel a few inches in normal air before it is brought to a stop by repeated collisions with the atoms in the air. While it is travelling very fast through the air of a cloud chamber its positive charge attracts many of the outer negative electrons of the atoms in the air, which may be drawn out of their original atoms, leaving them ionized. The alpha-particle passes so swiftly by that the electrons are left in its wake until it is brought to a halt at the end of its track.

The passage of one alpha-particle thus leaves a trail of ionized atoms behind it all along its track, each of which is capable of acting as a centre about which a tiny drop of water can form. If the alpha-particle is shot into the moist air of a cloud chamber just after a cooling expansion has taken place, so that the air is supersaturated, a trail of little water drops appears in its wake, looking just like the cloud trails left by a high-flying aircraft. In fact, the cloud trails left by aircraft are formed in exactly the same manner. Air has been cooled at the high altitudes but cloud has not formed because the air is so much cleaner and there are no nuclei. The agitation set up by the aircraft propellers is, however, sufficient to start condensation into the well-known vapour trails.

We have now got as near to seeing atoms as is possible—we can actually see and photograph the cloud trails left by them as they shoot through the cloud chamber immediately after an expansion has taken place. The time at which the expansion is to take place in order to catch a glimpse of the particles on their way through the chamber is very difficult to judge correctly. First of all the air in the chamber must be cleaned thoroughly so that no dust remains to fill the chamber with fog. This is usually done by making one or more preliminary large expansions to produce a "rain" which washes all the dust to the floor and leaves the air clean. If the expansion is made too slowly, more slowly than in about a fiftieth of a second, then the chamber will begin to warm up before the expansion is over and the cooling effect will be inadequate to produce supersaturation. The expansion must not be over too soon before the particle enters the chamber or the air will have warmed up again from its surroundings and the cloud trail cannot form. However, if the expansion is too late, the positive and negative ions will have recombined to form neutral atoms again and there will be no nuclei for condensation. It is a case of "not too soon, not too late—just right!"

Very often the chamber is used continuously on the chance of catching a rare atomic disintegration or cosmic-ray particle. On these occasions the ions produced by a previous atomic particle or by the stray ions

# PLATE V. THE WILSON CLOUD CHAMBER

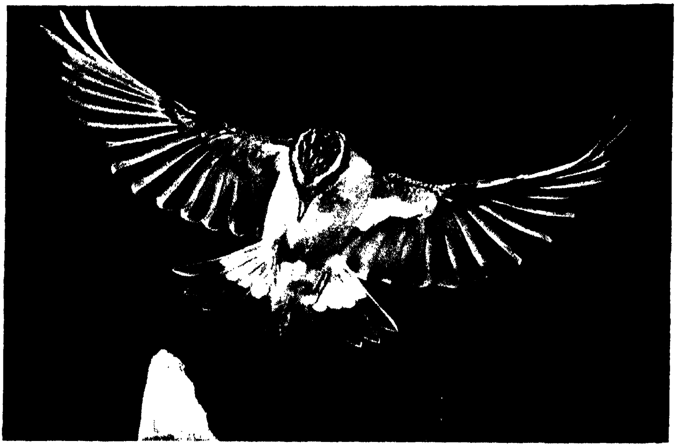


Cloud tracks made by ionized atoms
*(By courtesy of Prof. P. M. S. Blackett)*

Flying Saucers
*(International News Photos)*

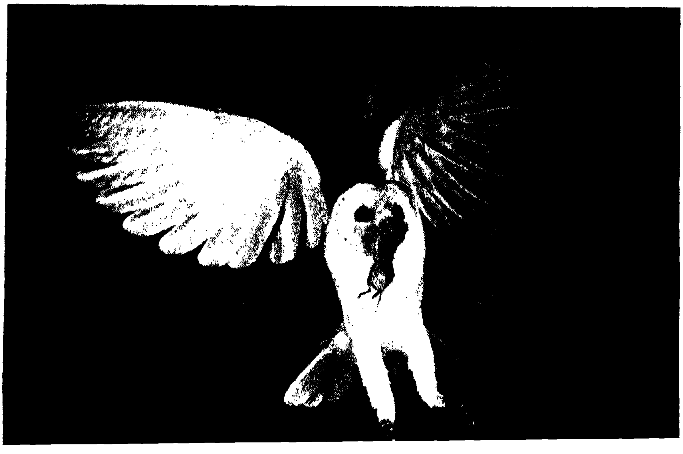
Cloud track made by B-29
*(By courtesy of "Flight")*

# PLATE VI. LORDS OF THE AIR



Cock
whincha
alighting
(*Eric
Hosking*)

Seagull gliding
(*Picture Post
Library*)



Barn owl
flying up,
with vole
in mouth
(*Eric
Hosking*)

often present in air, called "residual ions", must be cleared out of the way. This can be done by attracting them to the edges or to the bottom of the chamber by introducing an electric field between the metal rims shown in Fig. 1.

What sort of trails do we see recorded by the camera? It depends a good deal for what purpose the cloud chamber is used. There are two main uses: (*a*) to study nuclear disintegration; (*b*) to study cosmic rays—showers of particles arriving continuously from outside the Earth. Different types of atoms give different trails in the cloud chamber when they take part in nuclear disintegrations—they show up in the chamber because they are ionized in taking part in the reaction.

The first time that an atomic nucleus was split artificially was in 1919 when Lord Rutherford turned a nitrogen atom into an oxygen atom by bombardment with alpha-particles. This nucleus-splitting reaction has been studied by Professor Blackett with the aid of a cloud chamber. He obtained an actual photograph of this famous event (facing page 102). In this photograph a beam of alpha-particles appears as white trails crossing the chamber. One of them stops half-way as it hits a nitrogen atom in the air and the lighter trail of a proton (a positively charged hydrogen atom), knocked out of the nitrogen nucleus, moves off to the left, while the resulting oxygen nucleus (also charged by impact) gives a thick short trail to the right.

Photographs of this type show how the nuclear physicist identifies the different atomic particles—thick trails for heavy or highly ionized atoms, thin trails for the lighter particles, and the thinnest of all for the tiny electron, especially when it is travelling fast. We can also calculate the energy lost or gained in the reaction (important in nuclear fission) from the lengths of the trails, since the more energetic particles will travel further before they are stopped by collisions.

There is another method of identifying the particles, a method used in cosmic-ray physics. This method uses a strong magnetic field across the chamber so that the tracks of the particles are bent round in circles, one way for positive particles, the other way for negative electrons. The slower particles are, of course, bent more than the fast ones, so we can measure the momentum of the particles as they pass through the chamber.

It was with a cloud chamber in a magnetic field that an American scientist, Anderson, proved the existence of the positive electron in cosmic rays. He had some ordinary negative electron tracks curving to the left and a few others curving to the right. These could be either positive electrons (of "positrons") coming downward with the others, or ordinary negative electrons going upwards. Anderson proved they were coming downwards, and were therefore positive, by showing that the trails were bent more at the bottom of the trail, where they had lost energy after passing through a lead shield.

A modern design of cloud chamber like that used by Anderson in 1934 is shown in Fig. 2. This one is turned on its side between the poles of a strong magnet so that the cosmic-ray particles travel downwards across the chamber and across the magnetic field. When the release relay is worked it opens valve A connecting the space behind the piston, now a rubber diaphragm B, to the vacuum. The rubber bulges out so that the chamber expands. The camera takes a picture of the resulting trails in the mirror since it cannot be directly in front of the glass face because of the magnetic pole.

The two Geiger-counters are important additions to the modern apparatus. A Geiger-counter is a thin copper tube with a wire electrode up the middle and insulated from the tube. There is a fairly high voltage between the wire and the outer tube, which is filled with gas at a low pressure. When an ionizing particle passes through the tube, ions are produced which are attracted rapidly to the electrodes and which cause further ionization as they go. There is a resulting sudden pulse of current in the electrical circuits connected to the tube. This pulse of current can be made

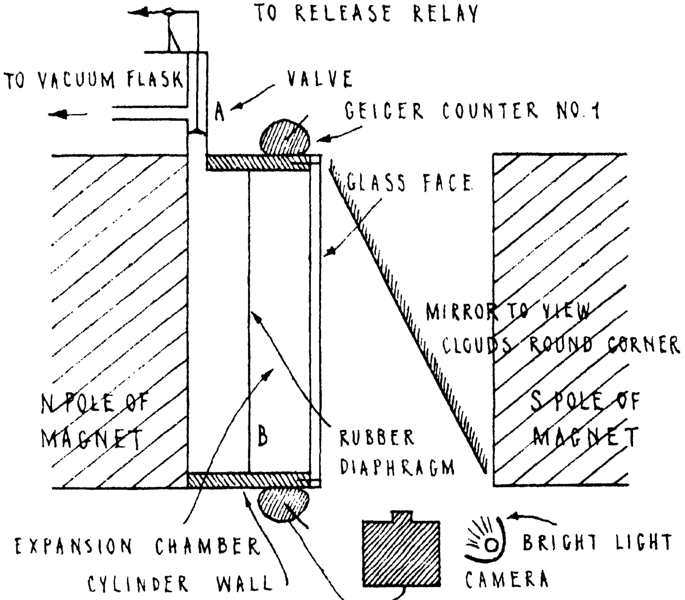


Fig. 2. A modern form of Cloud Chamber.

to operate the relay of a mechanical counter. The circuits may be arranged so that the relay operates only when both Geiger-counters fire almost simultaneously. If the relay sets off the cloud chamber it will thus be set off only if a particle has gone through both counters, that is, through the expansion chamber between them (Fig. 2).

We do not now need to waste time making continual expansions in the hope of catching a particle as it goes through; the modern cloud chamber will wait till one does go through, and then set itself off. Furthermore, we do not have to bother about getting just the right moment for the expansion, for this moment is just after the particle has gone through and before the ions have had time to recombine; the Geiger-counter circuits can be made to operate the chamber at this very instant. The same circuit may also work the camera and finally re-set the chamber ready for the next particle that comes along.

We have seen how an atomic particle can record its own passage through the cloud chamber and even take its own photograph. We have come as close as we can to actually seeing the invisible atom.

## ARE MOLECULES REAL?

In 1828 the botanist Brown reported that small pollen grains suspended in water move irregularly as though they were being kicked from all directions. Though the effect was discussed for many years it was only completely explained by the experiments of Perrin and the mathematical work of Einstein. Their results prove that the grains are being agitated—by collisions with the molecules of water. You need a low-power microscope to observe the "Brownian Motion"—and so to see evidence of the existence of molecules.

# Flying Saucers—What Are They?

B. C. BROOKES

FOR several years there have been persistent reports, mainly from America, that "flying saucers" have been seen in the sky. Though flying saucers have been variously described, most descriptions agree that these objects are rapidly rotating discs which are capable of high speeds and amazing aerobatics. What are they? What does the scientist think of them?

First it has to be noted that some hundreds of people claim to have seen things answering to the vague description of flying saucers. Some of these people have been men on whom we could normally rely for exact observation, as for example pilots of aircraft and airfield ground-control staff. On the other hand, some observers have admitted later that their accounts were simply hoaxes. In other words, some of the stories must be discounted—but even after making allowance for other possible hoaxers there is still plenty of evidence that demands an explanation. Unfortunately, no one on whom a scientist could rely to give a thorough scientific examination or description, as for example an astronomer or a physicist of repute, has yet been able to report on one of the things. Though some photographs have been taken of strange flying objects, photographs are notoriously easy to fake, and photographs that have been published show very little detail and are not very helpful. Descriptions of flying saucers are therefore very vague and widely different. Scientists would like to have more reliable evidence about the existence of flying saucers before they begin to consider them seriously.

We must not dismiss the possibility of there being flying saucers, however, just because we have no accurate and reliable description of them. The flying saucers are said to move very quickly, and so the aspect of them seen by people on the ground must also change very quickly. There are also suggestions that the flying saucers change their shape. If they do, it would not be surprising if reports appeared to contradict each other. It is also a fact that different persons' descriptions of an event differ very much even when the event is no more uncommon than a motor accident, and when the witnesses may all be within a few yards of the accident. It is not that the witnesses are dishonest and are lying deliberately; when they tell different stories each may be certain that his account is correct and complete. One of the tasks of the magistrate or jury in a court of law is to estimate the reliability of the witnesses brought before them. It is the task of scientists to estimate the reliability of scientific evidence that is presented on problems such as flying saucers. Let us then examine the evidence and also some of the theories that have been put forward to explain flying saucers—or to explain them away.

Most of the reports of flying saucers have come from the United States, and the Air Force authorities in that country began to investigate the reports. The Air Force had no alternative. The number of reports received was counted in hundreds and some had serious consequences. For example, it is said that an Air Force pilot saw a flying saucer from his aircraft and reported the fact to his ground base by wireless; he also announced that he was going to pursue it. He did so, and gave a running commentary on his pursuit until suddenly there was silence. Later his crashed machine was found; the pilot was dead. Tragic events of this kind have to be investigated. Even the loss of an aircraft has to be accounted for, but if a life is lost as well there is no escape from the responsibility of trying to find the cause of the accident so that similar accidents can be prevented in future. Moreover, in any country in the world the authorities who are responsible for defence cannot allow strange aircraft or missiles to fly over their territory without notice or permission; if there are persistent rumours of such happenings the government must investigate them. Then again, air-line operators do not welcome rumours that unknown aerial objects are using the recognized traffic lanes and not conforming to the internationally agreed flying codes. For all these reasons reports of flying saucers have to be investigated by somebody.

However, because the United States Air Force began questioning people who had reported having seen flying saucers, many other people immediately decided that "there must be something in them". "Where there is smoke there is fire," they said, and because they saw important officers solemnly taking notes about the rumours, it was easy to take it for granted that flying saucers were real and important things. Of all the reports that the Air Force investigated, about nine-tenths were explained as hoaxes, hallucinations, genuine mistakes, and so on. The remaining one-tenth were not explained, but this is not surprising. To explain nine-tenths was a remarkable success. After all, even our efficient police force does not claim to be able to solve *all* the crimes that are reported to it, and a crime leaves real, tangible evidence that the police can see and measure and analyse. Burglars leave footprints, fingerprints, broken windows, bloodstains, or blunt instruments; flying saucers come and go without a trace, leaving impressions only in the minds of surprised and excited observers. But it is time to look at some of the published reports.

Here are some descriptions collected, mostly from American newspapers, by Frank Scully; they are published in his book "Behind the Flying Saucers", but the descriptions given below are abbreviated:

1. Bright shiny saucer-like objects moving at 1200 m.p.h. at 10,000 feet.
2. Discs moving at 500 m.p.h. at 7500 feet.
3. A disc—not spinning—40 to 50 feet in diameter, moving at about 450 m.p.h.
4. A ball of fire, with short flaming tail, variously described as red, green, blue, and reddish-white.
5. Silver disc zig-zagging and leaving a trail of white vapour.
6. Tremendous aircraft spewing a forty-foot stream of fire from the tail, and with a fluorescent glow along its underside; speed about 600 m.p.h.
7. Egg-shaped object, of fantastic size, moving at 3 or 4 miles per second (10,000 m.p.h.).
8. A sky giant trailing a blue-flame exhaust nearly a mile long at 50,000 feet.
9. Ghostly trails coming from an invisible plane; a streak of smoke 15 or 20 feet long, at 20,000 feet.
10. A thirty-foot ice-cream cone, at 5000 feet, moving at about 85 m.p.h.
11. A blazing white object, changing from a flat and wide shape to an hour-glass and then to a disc.
12. Curved banana-like objects.

These are just a few of the hundreds of descriptions; in Scully's book you will find many more just as varied. What are we to make of them?

I think we can agree that it is difficult to reconcile all these descriptions of flying saucers. If you ask, "What are they like?" you are told they are big and they are small; they can fly at thousands of miles per hour and they can also hover; they are silvery, red, orange, yellow, black, and sometimes they change in colour; they leave smoky trails, burning trails, flaming exhausts of all the usual rainbow colours, and no exhausts at all; they are circular, egg-shaped, banana-shaped, tubular, conical, and spherical, and they also vary in shape; they are silent and they whine; they move in straight lines, play "tag" round mountain peaks, make right-angled turns at high speeds, go straight up and down, zig-zag, and disappear into nothingness. Is it possible? Is it surprising that reputable scientists do not take them seriously?

But let us try to be fair. In spite of the great variety of the descriptions of flying saucers it would not be wise to say that they do not exist simply because the descriptions vary. After all, the descriptions may vary because the flying saucers vary. Suppose we lived on a planet which had a very thin atmosphere, an atmosphere so thin that the flying of insects, birds, and aeroplanes was impossible. If six of us were sent to the Earth on reconnaissance, one of the most surprising things for us would be the sight of objects moving in the air. Some of us would notice big "flying things" with fixed wings that made an angry roar; others would observe small "flying things" that had beating wings and made chirping noises; others might report on "flying things" that seemed to have no wings at all. It would not be easy to realize from our reports that these "flying things" were of very different kinds. *You* may be able to distinguish between a Canberra, a goldfinch, a bee, a barrage balloon, a magpie, and a housefly, but imagine the confusion in the minds of the intelligence officers on our home planet as they tried to make sense of our six reports of "flying things" seen on the Earth. What size? From 80 feet wing-span to half an inch! What colour? Black, red and gold, yellow and brown, silvery, black and white, and steely blue! What speed? Six hundred miles per hour, thirty miles per hour, and no speed at all! What shape? . . . "Nonsense!" they would say to us, "You have been 'seeing' things!" It is true that many of the reports of flying saucers have varied because the things described have later been proved to be ordinary man-made or natural objects, but not all the reports have been disposed of in this way.

Though it may be difficult to sort out all the reports that are hoaxes, there are many reports left that must be accepted as genuine, if mistaken. Let us see how they can be explained as cases of mistaken identity, where the real thing is something we know of, or could accept as possible. The first explanation is that some of the flying saucers may have been meteors. The Earth is continually being bombarded by meteors. Occasionally at night you can see "shooting stars". These shooting stars are small meteors burning up in the Earth's atmosphere. They fall towards the Earth at great speed, and when they reach the upper layers of the atmosphere they are slowed down very abruptly by the resistance of the air. Though they are made of stone and iron they soon become hot enough to burn. The biggest ones last longest and may even reach the Earth's surface; others burn up almost completely on their way through the air. There are many more meteors than you might expect from a casual glance at the night sky; it is known that at some times of the year millions per hour fall on the Earth. They are thought to be the remains of a planet of our system that has disintegrated. Some of the bigger meteors that are captured by the Earth are visible in daylight, and these, it is suggested, may account for some of the flying saucers that have been reported. In other words, unusual real objects *can* be seen in the sky —and meteors may have been mistaken for something else.

There is another natural phenomenon which may explain some of the flying saucers. During thunderstorms the lightning strokes are usually of "forked" lightning; if you are two or three miles from the centre of the storm you can watch the vivid branching streaks that reach from the centre of the thundercloud to the ground. Sometimes, however, the lightning takes the form of a "fireball"—literally a ball of fire which can move haphazardly above the ground and disappear with an explosive flash. These fireballs have often been reported, but what they are is not known. Anyway, *some* flying saucers of the disappearing type may be fireballs.

Another possibility is that local disturbances in the atmosphere may be an explanation. During the War aircraft steadily increased their operating heights; photographic reconnaissance aircraft often flew at 30,000 feet. They were able to reach this and greater heights because they carried no guns, and they relied on their speed and climbing ability to escape from enemy fighters, which were of course handicapped in pursuit by the weight of their guns and ammunition. One of the advantages of flying at 30,000 feet and higher is that all the "weather" seems to be below you; the air is clear and usually free of clouds. As there are no storm clouds one would expect no "bumps", and yet curious things happened. Sometimes an aircraft flying in clear air would suddenly be buffeted and knocked about, sometimes so badly that the aircraft was damaged and even broken up. In spite of the clear air it seemed as though storms and turbulences did exist in the upper air, the more dangerous because there were no clouds to indicate their presence and intensity. The air that reaches western Europe has usually travelled for thousands of miles over the Atlantic Ocean and is comparatively free of dust; it may happen that some similar turbulences that occur over the dusty plains of the central United States make themselves visible as concentrations of dust particles, and are reported as flying saucers.

It has also been suggested that dust from atomic explosions and volcanoes may have reached great heights and have settled down in layers. In some states of the atmosphere and of sunlight such layers may have been observed and mistakenly described as flying saucers. In the past, curious effects have been known to arise from dust blown to great heights; violent volcanic explosions, such as the one that blew away the island of Krakatoa, gave rise to wonderful sunsets that were seen for months afterwards, though no one thought then of flying saucers. Whether atomic explosions cause smaller and more localized effects is not yet known; we have fortunately not had enough experience of atomic explosions to know or understand all the effects they produce. It is just possible, but not very convincing, to suggest that volcanic and atomic explosions are the origins of some of the flying saucers.

One other natural object may sometimes have been mistaken for a flying saucer, and that is the planet Venus. The planet is usually seen in the Northern Hemisphere as a very bright star near the horizon. It is called the "evening star" because it is often visible while the last rays of the setting sun are still reflected from high clouds. Seen through moving hazy clouds it might appear to be a bright light in motion, particularly if you were looking for curious things in the sky.

Meteors, fireballs, local air turbulences, dust from volcanoes and atom bombs, and the planet Venus, may be the natural causes of some of the rumours of strange flying objects. It seems unlikely, however, that they could account for all of them. What other causes could there be?

The second set of causes are those that can be called "psychological". So far we have described only things that either are well-known or that probably exist; in the next set we are going to consider "things" which exist only in the eye or in the mind of the observer.

Some people who think they have seen flying saucers may have seen only something in their own eyes. In our eyes there are specks or small "opacities" which we do not normally notice but which may become apparent when we look at a bright light or a bright sky. Moreover, the eye is fed with blood by means of small capillaries, and some people may occasionally see blood corpuscles moving across their field of vision. As the corpuscles and the opacities are inside the eye it is impossible to focus on them; they are seen, if at all, only as bright specks in the field of view, and it is not difficult to believe that they are outside the eye rather than inside.

Yet another optical effect may account for flying saucers. If you look at a bright light like the sun or an electric lamp and then look away, you may still "see" an image of the sun or of the wire of the lamp, probably in a different colour. These images can persist for some time—quite long enough to convince yourself that you have seen a real object. So, if you look up into a bright sky, particularly if you look directly at the sun, you may think that you see some object in the sky which in fact is nothing more than a well-known effect on the nerves of your eyes. (If you want to verify this—and you should want to if you are scientifically minded—try it on an electric lamp rather than on the sun, as the direct rays of the sun can permanently damage your eyes.)

One more possibility of this kind is that a pilot flying his aircraft at night may be distracted by seeing in the perspex before him a reflection of some light which is inside the aircraft. If the pilot mistakes this reflection for something outside the aircraft, another flying saucer may be reported. However, if you have ever flown with a good pilot you will realize how weak this explanation is. Pilots are trained to observe the sky incessantly and to note anything of interest they see; their eyes and ears seem to be working harder than those of their passengers. A slight change in the tone or throb of an engine is immediately noticed and checked against the instruments recording the engine's performance; the sight of another aircraft is an event that is satisfactorily explained only if the type of aircraft, the reason for its presence, its probable business, course, and destination can be guessed; clouds, lights, and vagaries of the weather are always of interest. It seems unlikely that a pilot could be as foolish as to be misled into chasing a reflection, yet it is just possible. On the other hand, if you agree that pilots are unlikely to be deceived into seeing flying saucers, you cannot also lightly dismiss their reports of them.

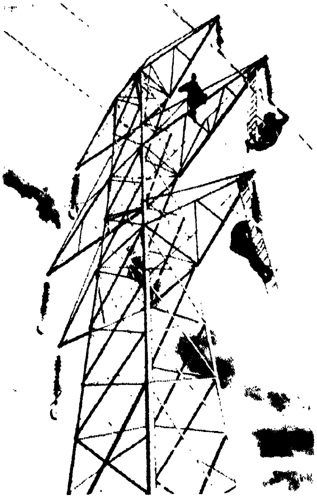
We also have to remember that there are many cases in which it is said that the flying saucer was seen, not by one person, but by several and sometimes by many people. While it is easy to believe that one man may have been mistaken, it is much more difficult to accept that fifty people can all make the same silly mistake. Yet we know this can happen. When curious things are talked of it is fact that many people succeed in seeing them, whether the things are there or not. One report of a monster in Loch Ness will yield a crop of similar reports. During the War every piece of debris seen floating in the sea became for some people an enemy submarine or a mine; anyone who had unusual though probably innocent habits was likely to be reported as a spy. If you stop in a busy street, point to an empty sky, and exclaim "Flying saucer!" you will probably find some passers-by agreeing with you. (You may also have to explain your conduct to a very sceptical policeman!) Talk of flying saucers, and some people will soon sincerely believe they have seen one—and the hallucination spreads among other people in the vicinity rather like an infectious disease. Still, it seems unlikely that these psychological causes account for all the reported flying saucers.

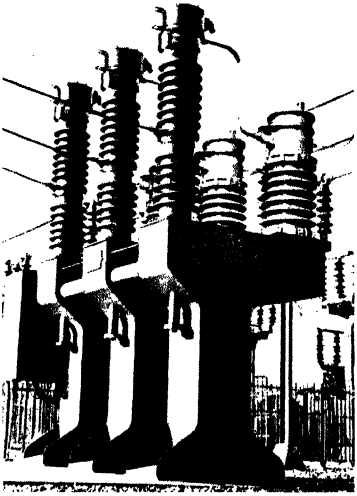
What else remains? It is definitely known that some man-made objects have been mistaken for flying saucers.

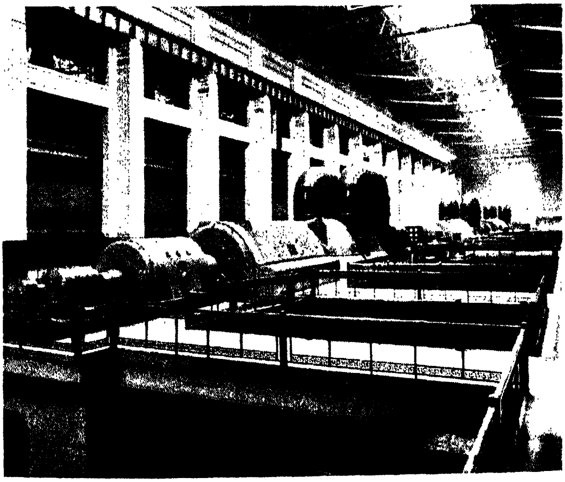
There are many scientific centres which use balloons to gather information from the upper atmosphere. Balloons carrying recording instruments are sent up from weather stations and also from universities where the department of physics is researching on cosmic rays. Sometimes the balloons are sent up in bunches of two, three, or four, tied together to support some unusually heavy piece of equipment. When such a bunch of balloons is seen from thousands of feet below, it would be difficult to see exactly what it was, particularly as parts of the shining surfaces of the balloons would reflect light from the sun brilliantly, and other parts would not. For example, on January 25th, 1951, a flying saucer was reported to be moving over southern Sweden at about 37,000 feet. Fighter aircraft from a training camp took off in pursuit but were unable to find the saucer. On the following day the professor of physics at a local university said that the reported flying saucer was known to be a bunch of instrument-carrying balloons released by scientists of his department. Balloons therefore explain *some* of the reported flying saucers.

Another piece of equipment that has been mistaken for a flying saucer is a wind disc, rather like a flat shuttlecock, which is used in the United States by meteorologists to determine the speed of the wind. It is released from an aircraft and falls at a steady rate, rotating as it falls; at the same time it is carried along by the wind. Observers on the ground can track these discs, and from the tracks the speed of the wind at various heights can be calculated. The discs are not more than a foot in diameter, and if they are seen from the ground they could be seen only as specks of light

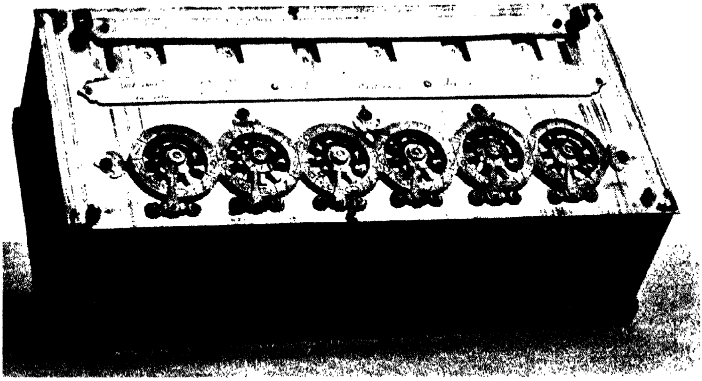
# PLATE VII. THE POWER ENGINEER


Clamping overhead conductors (*By courtesy of Messrs. W. T. Henley*)

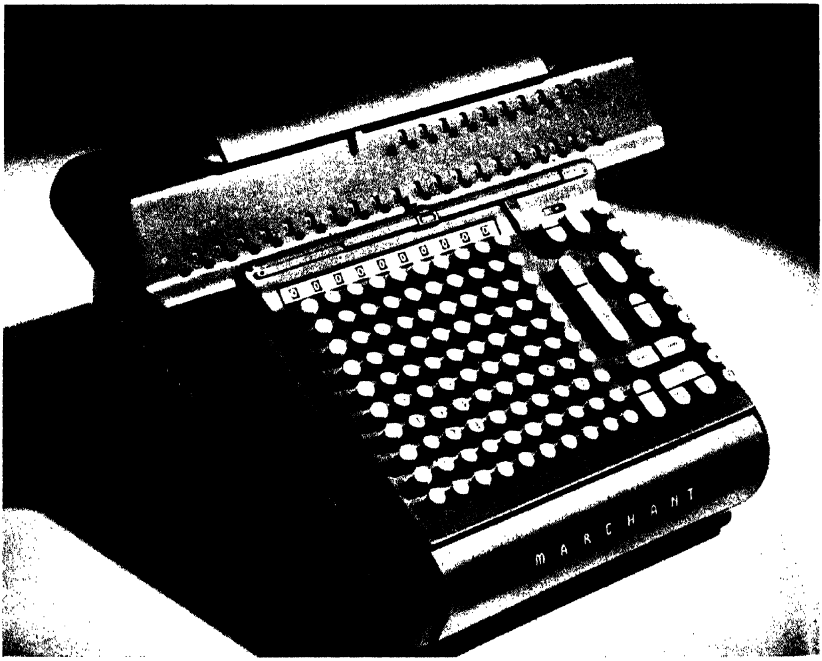

Current transformers and circuit breakers (*By courtesy of Messrs. Reyrolle*)


The Turbine House, Battersea Power Station
(*By courtesy of B.E.A.*)

# PLATE VIII. CALCULATING MACHINES



Replica of Pascal's calculating machine (1642) (*Crown copyright from an exhibit in the Science Museum, South Kensington*)



Modern electric-powered calculating machine

(*By courtesy of Block and Anderson*)

reflecting the rays of the sun from their vanes. If they are not recognized as wind discs they can easily become flying saucers to people who see them, particularly as the wind speed and direction at a few thousand feet can be very different from those on the ground.

Strange new aircraft are seen in the sky from time to time—perhaps you remember seeing your first jet aircraft. In war-time very little is publicly stated about new aircraft designs; many people must have wondered what the first screaming jet aircraft were, because they were seen in flight for months before any official announcement about them was made. Development of new designs goes on, and in these uncertain times new aircraft with unorthodox wing-shapes may be seen on flying trials before their existence is officially admitted. It is known that some flying saucers reported have been public glimpses of new aircraft undergoing flight trials.

There are also experimental guided missiles on trial in the United States; we know that work is proceeding on rockets like the German V2. Occasionally these experimental rockets misbehave themselves and go the wrong way—more flying saucers are reported. In America it was first thought that the flying saucers described as acrobatic flying discs were some new type of missile under test. It was officially denied; whereupon there were two interesting public reactions. Some thought, "They have denied it; therefore it must be true", on the grounds that the United States authorities would wish to keep the new weapon secret. Others thought, "If the missiles are not American, they must be Russian", though it is not easy to see why the Russians, if they had such new weapons, should give away their secrets to the Americans by sending them harmlessly over to Oregon and Arizona. The Russians have not denied that the flying saucers are Russian. Why should they? And who would believe them if they did? In any case, whatever officials say, people who want to believe in flying saucers will go on believing in them.

We have now looked at some of the explanations of the flying saucer rumours that have been given by scientists. Though some people are satisfied by them there are others who are not. Even some scientists might admit that there may be still something yet to be explained, though scientists in general would expect that explanations similar to those already given could explain all the genuine reports of flying saucers. There are people, however, who still believe that flying saucers are real things, and who have some rather extraordinary explanations of them. Some say that the saucers come from another planet, probably Mars. According to this theory the flying saucers are space-ships on reconnaissance over the Earth. They carry Martians who are beings with the same kind of intelligence as ourselves but who are very much smaller and probably like large bees. This theory is difficult to refute because nobody has yet found a flying saucer. The theory is equally difficult to uphold for the same reason. It might account for the fact that we have not found a flying saucer—the reason is that they have all flown back to Mars! Even if a flying saucer did fall down on the Earth, it has to be admitted that the chance of it crashing in some accessible place is small. Most of the Earth is covered by water, and much of the land is high mountain, desert, thick forest, or ice. Large meteors have been known to fall on the Earth from time to time, but all the big ones have fallen, so far as is known, into the oceans or into remote places like Siberia and Arizona where their craters have been discovered long after the event. Flying saucers may be small, perhaps only a few feet in diameter; objects as small as this could easily come down on the Earth's surface away from the sight of man. So the theory could be argued; but though it may satisfy some people it does not satisfy scientists or astronomers. Theories that are based on the absence of something are less convincing than theories that are based on the presence of something. There are many other theories just as entertaining as the Martian one that could be put forward and which could equally well not be refuted. For example, the theory that the flying saucers contain intelligent snakes from the Moon would be just as difficult to disprove, particularly if it were upheld by an obstinate and astute man with a wide knowledge of science.

You may wonder why the occupants of the Martian flying saucers are thought to be bees of some kind. There are two reasons. The atmosphere of Mars is known to be thin and to consist mainly of carbon dioxide. Life for people like ourselves would be very difficult on Mars, but insects might be able to live there. The designers of flying saucers must be very intelligent beings; bees are intelligent insects; therefore the occupants of the flying saucers are probably Martian bees. So the argument goes. The second reason is that though Mars approaches the Earth more closely than any other planet, it is still about 40,000,000 miles away at its closest. It would take a man much longer to fly that distance in a space-ship than a bee. Though, so far as we know, there is nothing to prevent a man from moving at a steady speed in a straight line at 1,000,000 miles per hour, it would take him a long time to reach that speed. The limiting factor is not the high speed itself, but the high acceleration and deceleration needed to make use of such speeds. A bee, weight for weight, is much stronger than a man and could therefore stand much higher accelerations. Even so, 40,000,000 miles is a long way.

And why should the bees come to the Earth? The answer is that they have noticed atomic explosions on the Earth and they are worried lest these explosions are indications that the Earth is about to disintegrate. If the Earth should disintegrate into dust it would form a screen between Mars and the sun. As the amount of heat and light received on the surface of Mars is much smaller than our share, life on Mars (if there is life there at all) might perish from cold, if the dusty remains of the Earth cut down the sun's rays, already weak.

This theory is attractive because it is imaginative and because it cannot be completely disproved until someone captures a flying saucer and shows it to be something different. Even then it will be possible to argue that the captured flying saucer is not a "real" one!

Another imaginative theory is that the flying saucers come, not from Mars, but from our other planetary neighbour Venus. The planet Venus moves on an orbit which is nearer to the sun than the Earth's orbit. Very little is known about the surface of Venus because it is always covered by a thick layer of cloud. It is suggested that the passengers in the flying saucers from Venus are men of the same general build as ourselves but of about one-third of our average height.

Some of the reports that support this theory have been very detailed, perhaps too detailed to be convincing. According to one story a complete flying saucer landed almost undamaged in America. It was made of a metal like aluminium but lighter and harder, with a melting point so high that it has not yet been possible to melt it. The little men were all dead. There are so many important facts about these little men we should like to know, but we are told only such odd things as that they had no fillings in their teeth. We are told vaguely that the saucer was driven by a magnetic motor based on a principle not yet understood. We are also told that the outer diameter of the motor was 99.99 feet, and that it had inner diameters of 72 and 45 feet. (Note the curious precision of the first measurement, correct to about a tenth of an inch, and the rough values of the other two, correct to the nearest foot.) These measurements are said to show that the little men use the same arithmetic as ourselves, because the three numbers are divisible by 9. It seems to have escaped notice that the measurements are obvious multiples of 9 partly because of the different accuracies with which they have been measured, and partly because they have been measured in feet. It is flattering to find that the inhabitants of Venus have adopted the British measure of length, thought to be so inconvenient by our Earthly neighbours on the Continent. Another interesting detail is that the flying saucer is said to have contained what the house agents call "modern conveniences", which proves that the trip from their home took more than an hour or two!

Altogether this report reads rather like a poor hoax. The details are so oddly mixed, some so strange and some so conventional, that it does not even make a good story. How much better a story H. G. Wells or Jules

Verne could have made of it! Why has this saucer not been scientifically examined? Some information about such a machine might be of military value, and we could understand why it is withheld, but a biological description of the little men would be of enormous interest to scientists. Why are we not told? There is an obvious answer.

Scientists do not accept the more imaginative theories about flying saucers. They do not say that it is impossible for the flying saucers to be visitors from another planet; they say only that it is very unlikely and that their own explanations are more likely. On the other hand, a good scientist is always ready to change his mind if new evidence is produced, but scientists quite reasonably ask to see a flying saucer "dead or alive".

It is perhaps a pity to learn that the mysterious flying saucers are unlikely to be visitors from another planet; that they are more probably rather ordinary things whose identity is mistaken. Yet there *may* be something in these stories that science cannot yet explain. Do not be surprised if the flying saucer stories continue to be reported; and when you read or hear one try to account for it in the scientific way rather than by accepting another imaginative theory, however exciting it may be. Science is not yet so dull that we need to imagine exciting new discoveries. The case *for* flying saucers is so far "not proven", but neither is the case *against* flying saucers wholly proved. So keep your eyes and ears (and mind) open to receive and criticize any new stories you hear.

# Lords of the Air

### G. J. BOLTON

NEARLY all of us at some time or another must have stopped for a moment to observe the graceful, deliberate movements of a bird in flight. We notice the effortless way in which he alights and takes off again, winging his way round the chimney pots, wheeling and turning in the air, until he comes to land again. Every movement he makes is poised, certain, rapid yet unhurried. I wonder how many of us have thought any more about it? Why is it that, with a few exceptions, birds are the only members of the vast animal kingdom that are able to fly. How do they steer? How do they gain height? How are their bodies fitted for this strenuous activity?

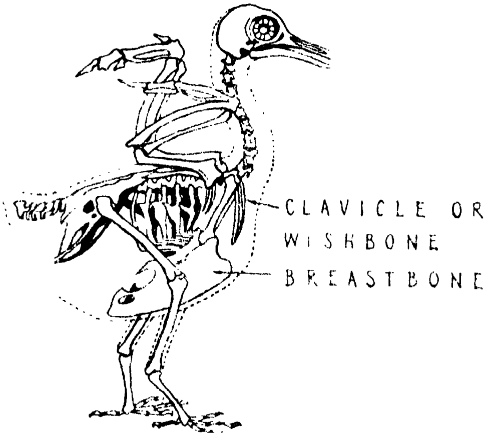


Fig. 1. Skeleton of a bird—note the well-developed breastbone for the attachment of flying muscles.

On investigating we find that not only the wings and tail, which are obviously used in flight, but the whole body of the bird is a wonderful structure, perfectly adapted for flight. The skeleton (Fig. 1) is lightly built, yet at the same time it provides large surfaces for attachment of the muscles to work the wings. Some of the bones are joined together to give strength to the frame. In addition, the bones instead of being filled with marrow are hollow, and if we cut one across it will appear to have the open structure of a sponge.

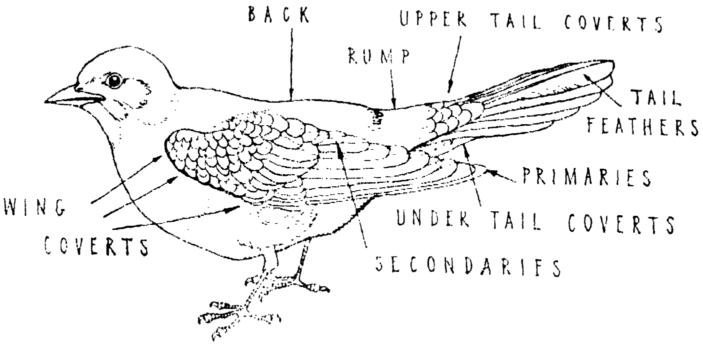


Fig. 2. The main groups of feathers.

This arrangement lightens the weight of the skeleton, and at the same time increases its strength.

Throughout the body we find air sacs, some of them even between the muscles and the skin. There are six of these sacs, each one connected with the lung. When the bird is in flight air is pumped throughout the bird's body. A large supply of air is required, as much energy is used up in flying, and without a good supply of oxygen the food cannot be broken up and used to give the energy.

The feathers are probably the most important part of the bird's flying equipment, and wonderful structures they are; perfectly formed and designed for the work they have to do. There are various types of feathers distributed over the body of the bird and a glance at Fig. 2 will make it easier for you to understand the position of the feathers, as they are referred to in the text. Notice that the whole body of the bird is covered with short covert feathers. These have two functions. They keep a layer of air trapped in contact with the skin of the bird, and so keep it warm. The same principle applies to your own clothes. In addition, the covert feathers give a smooth surface to the bird so that it offers little resistance to the air when in flight.

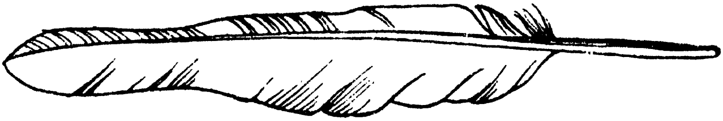


Fig. 3. A quill or flight feather.

On the wings are the primary and secondary quill feathers. These are probably the most conspicuous feathers on the bird when in flight. The primary feathers are carried on the bird's "hand", the secondaries are on the "forearm". There are no quill feathers on the upper arm. Before we discuss the use of their wings in flight, we must first examine one of the feathers that make up the wings. Get one for yourself and look at it (Fig. 3). Notice that it can be bent double without breaking; this great flexibility prevents it from snapping off in times of sudden air pressure on it. Notice how light in weight it is (all the feathers off a *big bird* only weigh a few ounces). You will see also that it is very slightly curved to enable it to fit closely to its immediate neighbour in the wing. Next try holding it between your fingers and swing it through the air, with the sharp edge leading; it offers no resistance to the movement. Now turn it so that the flat part is perpendicular to the direction of movement and the resistance to the air feels very considerable. Next try pulling the barbs apart; you will find that they separate with difficulty; next smooth them over and they stick together as if they had never been parted. If you look at Fig. 4 you will see the reason for this. The feather has a shaft, off which numerous barbs radiate. These barbs in turn carry numerous barbules, some of which are hooked and called barbicels. The hooks of one interlock with the adjoining barbule and so give the

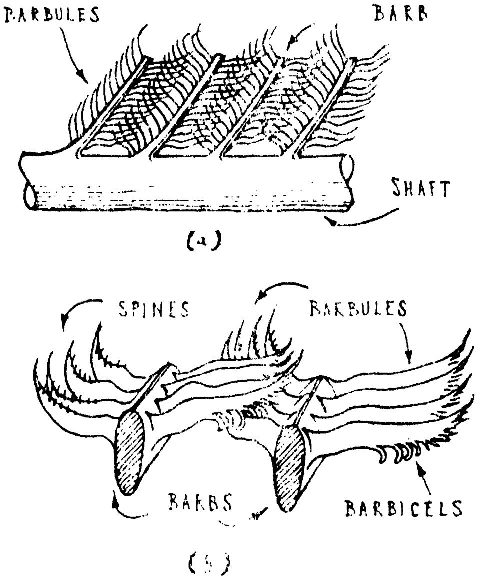


Fig. 4. The structure of a feather: (*a*) magnification of part of feather; (*b*) magnified cross-section of adjacent barbs.

feather strength, combined with flexibility. If you are able to examine the whole wing of a bird, notice that the vane of the feather is not the same width on both sides of the shaft. One side is narrower than the other and is the "leading edge", the trailing edge is broader in order to overlap with the feather behind. Sometimes the leading edge is not a constant width all its length, but narrows suddenly towards the tip. This is very often seen in game birds like the pheasant and partridge, and it gives them more control over the air in flight.

Quill feathers are also found in the tail. They differ from the wing quills in having the vane equal in width on either side of the shaft. These tail quills are most important for steering the bird in flight and also for braking. When next you see a bird coming in to land after a flight, notice that just before its feet touch the ground, the tail quills are pointed vertically downwards! This stops the forward movement of the bird and prevents it from over-shooting its landing place. This is a very important piece of equipment when you think of making a landing on the top of a post or on a telephone wire.

Now that we know something about the various feathers, let us see how they are used in the movement of the bird through the air.

To raise itself off the ground the bird stretches out its wings, and keeping each feather tightly pressed on its neighbour it uses the wing to beat on the air, so lifting the body off the ground. As soon as the bird is airborne the whole weight of its body is carried by the wings, so we find well-developed chest muscles to work them, and also a large keel or breastbone to form a strong point of attachment for these muscles.

The photographs show the beginning of ordinary flapping flight. In this method of progress through the air the stroke commences with the backs of the wings almost touching over the bird's head and slightly in front of it. The strong muscles pull the wings down and back, so driving the body of the bird upwards and forwards in the air. At the end of the down stroke the wings are pulled up again by a different set of muscles, and the force of the air on top of the feathers opens the primaries, allowing the air to spill between them and cutting down resistance. This is the most common type of flight employed by a bird determined to reach an objective, for example, on a migratory flight. The tail quill feathers are used as a rudder. If the bird wishes to turn in the air, the body is tilted over by the tail feathers, and the wing on the outside of the turn beats faster, so bringing the bird round in the air.

When at the seaside you may have seen birds soaring overhead. When the bird is soaring the wings are held straight out on either side of the bird, and it makes use of upcurrents of warm air to increase its altitude. This is the same principle used by glider pilots, who, having no engine to draw them along, are forced to rely on air currents if they wish to remain aloft for any length of time.

It is also possible to see birds in the act of gliding flight. When gliding the wings are held straight out as they are when soaring, but they always lose height when gliding, and it is frequently used when the bird is returning to its nest.

In addition to the modes of flight already discussed you may have seen birds of prey, owls or eagles for example, apparently remaining still in the air, watching their intended victims on the ground. This is known as hovering, and when doing this, the bird's wings are flapped slowly straight up and down, so that there is no forward pull at all, and just sufficient effort is expended to prevent the bird losing height.

No discussion of types of bird flight would be complete without reference to the dive of certain sea birds, for example the gannet, when going after fish. The bird spends some time hovering, about one hundred feet above the sea, until its very sharp eye catches the silvery gleam of a fish several feet below the waves. The bird's wings are then laid flat on its back, the tail stretched straight out behind, and the feet and the legs tucked tightly in underneath the body. The bird then dives at a high speed straight into the water, to emerge triumphant with the fish in its beak.

Having discussed the ways in which the wings are used and moved in flight, we must ask ourselves why these particular wing movements actually do lift the bird into the air.

The lift on the wing at any one time is made up of two components, namely, the pressure of the air on the underside of the wing, and also the lift provided by the suction pressure or vacuum caused by the flow of air over the convex upper surface of the wing. The latter is the more important. As long as the wing is held nearly horizontal, that is to say, presenting a small angle to the direction of air flow, this lift is at its maximum. If, however, the wing is tilted, and becomes steadily more nearly vertical, air eddies form over the trailing edge and slowly destroy the vacuum lift until eventually the lift is destroyed completely and the wing is in the stalling position. Stalling can be reduced by making the air flow more evenly over the wing. In aeroplanes this has been achieved by the slotted wing. This is a small auxiliary wing placed in front of the leading edge of the main wing. In birds precisely the same effect is brought about by the bastard wing, a small wing in front of the main wing, and in addition by the narrowing of the primary feathers towards their outer edges. This latter arrangement allows the wing tip to be broken up into a series of slots which help to reduce the air eddies over the wing.

Having discussed the mechanism of the bird's flight, we can now consider the sensations experienced by a bird once it is in the air. This is a subject on which many false ideas are often expressed. This is due to the fact that we who are tied to the ground have difficulty in imagining the feelings of an animal moving free in the air. It is all a question of relative velocities. Let us imagine the bird flying forwards at 30 m.p.h. in completely still air. Its ground speed will be 30 m.p.h. in the same direction. Now let the bird continue to fly at the same speed, but instead of flying in still air, suppose it is flying into a head wind of 20 m.p.h. Its actual land speed will then be 10 m.p.h. The bird, however, will not notice any different sensation. Thus it is wrong to say that birds are seen struggling against the wind. Their efforts are the same, the difference is in the time taken to cover a given distance, and if this time is too great the bird may become exhausted. This is perhaps not important on inland flights, when the bird can come down and rest on any convenient landing place. On long-distance migratory flights, however, a head wind may reduce the distance covered by a bird so much that it is unable to reach land before becoming exhausted.

Have you ever wondered how birds find their way on the immense migratory flights of 3000 or 4000 miles which they undertake? It is an interesting question, and one about which we have still much to learn. Take the swallows for example: every autumn they form into flocks and make their way to South Africa, using two quite well marked routes. Some follow the west coast of France and Spain, cross the Straits of Gibraltar, and continue to follow the west coast of Africa. Others cross Germany, fly over Italy, and after a fairly short crossing of the Mediterranean they arrive over Egypt. From here they follow the east coast of Africa. In both these routes we find that much of the way is marked by a coastline or beach, which may be used by the birds as a kind of map; we do not know. They may also use the position of the sun to guide them, and some of their route-finding may be by that mysterious power, instinct. It all sounds quite simple when you think of an old bird that has done the journey before. Think though of the nestling, hatched in May in England; although it has never made the journey before, it sets out in autumn with the rest, to make the journey to South Africa. Perhaps some day with further observations we may be able to understand more of this truly wonderful route-finding; at present it must remain something of a mystery.

Finally, perhaps the speeds of various birds in the air may be of some interest. Among the slower birds we find the jays, blue tits, cuckoo, raven, and sparrow hawk. All of these have been timed to fly at between 20 and 25 m.p.h. It must be remembered that these figures are approximate, as they are obtained from actual observations, and we have no means of telling whether the bird was flying at its average or maximum or minimum speed at the time the observations were made. Among the faster birds we find the golden eagle and the black vulture, which have both been observed doing 120 to 130 m.p.h. A peregrine falcon has been seen to do 200 m.p.h. in a stoop, that is to say, in a dive on to its prey. Between these two extremes of speed we can roughly place all the other birds, remembering all the time that observations on this subject must be inaccurate. For one thing they may have to be made from a car in contact with the ground, whereas for the bird flying alongside the car we can only give the land speed, and not the more important air speed, taking into account the velocity of the wind. When discussing the air speed of birds we must not forget that the velocity of the wind, aiding or impeding the bird, is not the same at all altitudes. For instance, one set of figures show us that when the wind velocity on the ground was only 11 m.p.h., it was 65 m.p.h. at 10,000 ft. and 100 m.p.h. at 30,000 ft. For this reason many birds on migratory flights may go to a considerable height to take advantage of the higher wind velocity, if it happens to be in the right direction.

It is difficult to make any general remarks on the heights reached by birds, simply because of the difficulty of having an observer at 10,000 ft. for some time to see if birds do come up to that height. However, it is reported that godwits and choughs have been seen on Mount Everest at over 20,000 ft., and again in India a photograph of an eclipse of the sun shows a flock of geese deduced to be at 29,000 ft.

Perhaps by now you will have gained some idea of the principles underlying flight and the great advantage this power is to the birds, and you will have picked up some thoughts about speed and direction-finding. The next step is to watch the birds yourself, to see if you can pick out the various types of flight, and the uses of the various feathers. Try to estimate the speed of flight of birds you see, and perhaps keep a notebook of the observations you make. They are interesting and beautiful creatures, spread all over the world, and the hours spent watching them are amply rewarded.

## A NOTE ON CHESS STRATEGY

The Sicilian Defence, (1) . . ., P–QB4, is recognized by most good players as the best reply to (1) P–K4, though beginners still seem to prefer the well tried (1) . . ., P–K4. This move often leads to a game full of tactical traps, but offers little hope of carrying out a general strategical plan. The ability to win a game by long-sighted strategy rather than by traps is characteristic of the stronger type of player; you should try to develop the *strategy* of chess playing.

The object of the Sicilian is an attack by Black on the Queen's side. White should attack on the King's side, and if your opponent does not do this you should win. The strongest game for Black (the "Dragon Variation") begins: (1) P–K4, P–QB4, (2) Kt–KB3, Kt–QB3, (3) P–Q4, P × P, (4) Kt × P, Kt–B3, (5) Kt–QB3, P–Q3, (6) B–K3, P–KKt3, (7) B–K2, B–Kt2, (8) Castles, Castles.

Playing Black, you should note the following points. First, never exchange your King's Bishop; it is a vital defensive piece which must remain at Kt2 as long as possible. Secondly, P–K4 is almost always bad for Black as the Queen's Pawn is left weak. And lastly, remember that your plan is a general attack on the Queen's side.

*CAREERS IN SCIENCE II*

# The Electrical Power Engineer

A. P. BEALE, B.Sc. (Eng.)

THE most fascinating thing about electricity is that it can hide immense power in complete stillness. If you go into a sub-station, where the high-voltage power on the grid is transformed into lower-voltage power that can be used in home and factories, there are only three thin metal bars held on the top of porcelain insulators. And yet through these thin bars runs power equal to that of an engine of perhaps 20,000 h.p., or even more. The control of such immense power is a work of great responsibility, and the electrical engineers who do it must have a thorough training in the theory and the practice of electrical power. But before we can understand what electrical power engineers do, we must know a little about how the electricity supply industry works.

In England electrical power is made at generating stations run by steam turbines or by diesel turbines. In Scotland, where the mountains are high enough, water stored in lakes high in the mountains can be used to drive water turbines, but in Great Britain as a whole not much power is made in this way. All the big power stations near London have turbines driven by steam, and it is very important that there is an easy way of getting coal to the power stations. Most of London's power stations are on the banks of the Thames, so that coal can be brought up in barges. There is another advantage in building a power station on the banks of a river, and that is that the river water can be used for cooling; a great deal of water is needed for cooling in a power station, and a river supplies the water more cheaply than any other method.

When the electrical power has been generated, it is taken away from the generators by cables which lead on to bus-bars. These bus-bars are copper bars about three inches high by half an inch wide. Before the power is transmitted over long distances, the voltage is changed by transformers. This is done because to transmit a large amount of power over long distances a high-voltage line is always more economical than a low-voltage line. When power is sent at a low voltage, the current must be high. The high current makes the wires heat up, and much power is lost in the form of heat radiated from the wires. When the voltage used to send the power is high, however, the losses due to heating are much lower. In England the normal transmission voltage for sending power over long distances is 132,000 volts. This is the voltage of the National Grid. Experiments have been made in England with higher voltages, and some foreign countries, especially European countries, are actually using higher voltage. In Sweden, for example, they are using 400,000 volts over one short stretch of line.

The generators do not make the power at these high voltages, however. But the power from the generators is changed to high-voltage power by transformers, and then fed on to the transmission lines. At the power stations there are elaborate switches, so that if anything goes wrong with a transmission line or generator it can be shut off from the rest of the network and repaired.

There are two types of switch, one called a circuit breaker and the other an isolator. The circuit breaker can be opened or closed while the full current is flowing through it. Circuit breakers are used for all normal purposes. But if the line has to be repaired, the repair gang want to be sure that no one can switch on the circuit breaker by mistake. So the isolators are opened at either end of the piece of line to be repaired, or on either side of the faulty piece of apparatus, the switching in this case being almost always hand-operated. The circuit breaker is opened, and then the isolator. If someone switches the circuit breaker on by mistake, then no current will flow through the open isolator to where the men are working, so they are safe. The isolators cannot be opened when the full current is flowing through them, because they are not strong enough electrically to do so. And it would be impossible to make them strong enough without costing a lot of money.

The main transmission lines in England work at 132,000 volts. These lines are carried on steel pylons, which can be seen in almost every part of the country these days. But this voltage is too high to be used in homes and factories, where the normal voltage used is either 230 or 400 volts. So the power has to be transformed down again to a lower voltage. All these changes of voltage may seem to be unnecessary and wasteful, but for sending power over any distance above a mile or so it is always more economical to use a high voltage, at least 6600 volts. As the amount of power to be sent from one place to another becomes greater, so the economical voltage becomes higher. So there are many transformers in every electrical network. Generally these are controlled by switches, so that if the line goes wrong it can be switched off. These transformers and switches must be looked after and examined from time to time to see that they are still in order.

At the present time the generation and transmission of electrical power in England are controlled by one part of the British Electricity Authority, and the distribution of electrical power by another. These phrases are rather technical, and what they mean is this. One part of the B.E.A. generate the power in the power stations, such as Battersea or Barking. They also look after main transmission lines, called grid lines, which run at 132,000 volts, and they control the sub-stations where the voltage is transformed from 132,000 volts to 33,000 volts. The rest of the electricity supply industry, from the 33,000 volts bus-bars to the factory or home, is controlled by the distribution part of the B.E.A. The distribution of electric power from 33,000 volts to homes and factories entails several things. Power lines must be built to carry the power, the lines being either overhead lines on poles or underground lines in the form of cables. There must be numerous sub-stations where the power is transformed from one voltage to another, and where there are switches so that all sections of the line can be controlled. In the final stage of the distribution the power reaches the person who wants it. A meter is put in his house or factory so that the amount of power he uses can be measured. Providing he takes all the power he uses through the meter he can take as much as the cable leading to his house will stand (although in these days of power cuts that is not quite true, because it isn't always possible to generate as much power as people want). But it is unwise to learn a little about electricity and then tap the cable before it gets to the meter, so that you get free power from the Electricity Authority. There are severe penalties for that sort of thing! At the consumer's terminals the job of the power engineer ends. His job is to see that a constant supply of power reaches those terminals at all times of day or night, seven days a week, fifty-two weeks in a year.

In the supply industry there are three main branches to which the engineers belong. They are Planning, Construction, and Operations and Maintenance. The easiest way to see what sort of jobs a power engineer may have to do is to consider these branches one by one.

The engineers in the planning department make out plans for all types of lines. They must understand the theory of power supply well, because sometimes they have to think out cheaper ways of doing some particular job. They look at a plan of the area to be supplied and say: If we supply it from one end, the line will be straight but the poles must be very high because it goes over an orchard; if we come from the other end, we can use shorter poles but the route is not so direct. They must then be able to work out the relative costs of the two schemes, and decide on the one which is generally more economical. The planners must remember many things, such as the possibility of somebody building more houses in the area, in which case they will need to give more supply and may have to use underground cables instead of overhead lines. There may be legal difficulties in getting permission to cross over a particular bit of land, in which case it might be better in the long run to go round a slightly less direct route. The planner must be an engineer who looks a long way ahead; it is a very interesting job.

The other two branches are rather more practical and down to earth. The construction branch puts the planner's ideas into practice. From the plan comes the line, and the construction engineers have to overcome all the practical snags in building the line. When a plan has been approved, one of the engineers goes out and surveys the line accurately. He shows on his plan exactly where all the poles must go, and sees whether the poles are likely to need any support to prevent them leaning over when the wires are put up. After this another member of the construction department gets permission for the line to cross over the different owners' land. When this has all been done, the construction gangs go out, put up the line, and do whatever jobs are required. The construction engineer is responsible for getting all the stores and the men to the right place at the right time, not always as easy as it sounds. In addition, the more senior constructional engineers must advise when more complicated apparatus is being put up, and must always watch carefully when outside firms are doing work by contract. This means that they must have spent several years in constructional work, dealing with all the many things that go to make up an electricity supply network.

The engineers in the operations branch are the men who really keep the supply going. They control the sub-stations where the various parts of the network can be switched on to the supply, and they have to watch the meters which tell them whether the supply is coming through satisfactorily. When something goes wrong it is called a "fault". Faults are either reported by the outside public—when their supply is cut off, for example—or the operations engineers see that something is wrong from the meters on their switchboard. Much of the operations engineers' time is spent in finding out where a fault has happened and then mending it. Very often a fault happens at night, and something is always more likely to go wrong in bad weather. The engineer may spend all night out in the winter, trying to discover where some overhead lines are down or are fouling. In addition to this, the operations engineer is responsible for keeping all the equipment well maintained. He must arrange to have the overhead lines patrolled and tested from time to time. The underground cables and all the switches must also be tested and examined. The engineer must also see that all firefighting apparatus is kept ready and in good order. There are many dangers in the transmission and distribution of electric power, and one of the most serious is the danger of fire.

The job of the power engineer is one of great responsibility, and the power engineer must be clever both theoretically and with his hands. He must be able to look ahead and see where improvements can be made, and must have sufficient knowledge to be able to put any faults that happen right. He must also be prepared to accept a little bit of abuse with good humour. Whenever anything goes wrong, he is always blamed. Most people never bother to think that a lot of work goes into keeping the supply going, and the length of time that supply is shut off is very small compared with the time it is on. Lastly, there is plenty of variety in the power engineer's job. He has to be out all weathers, he has to sit at his desk and work out problems. It is a job for a man.

So far I have described very briefly something of what an electrical engineer does. But how do you become an electrical engineer? You can say that you are an electrical engineer when you have got the Associate Membership of the Institution of Electrical Engineers. You can then put the letters A.M.I.E.E. after your name, and when you apply for a job everyone knows that you are a properly qualified electrical engineer. To get an A.M.I.E.E. takes about seven years, starting from the time you leave school with a General School Certificate or its equivalent. This seems a long time, but only three years are spent in full-time study, without earning any money. The rest of the time you do get some pay, although not very much to begin with.

There are two main ways of training to be an electrical engineer. The first is to go to a university or technical school for three or four years, at the end of which you will have a degree or a Higher National Certificate—providing, of course, you pass the examinations! Then you do two years' apprenticeship, as a graduate apprentice, and finally two years working in a responsible position. That makes up the seven or eight years, and you can then apply to become an A.M.I.E.E. The second way is to work for a firm of electrical engineers for five years as an apprentice, studying at evening classes to pass the examination of the Institution of Electrical Engineers. After that you do two years in a responsible position, and then you can again apply to be made an A.M.I.E.E.

The descriptions above are very brief, so I will explain the training in both cases more fully. The university course lasts for four years, and is intended to give a broad idea of engineering in the first two years, with specialized training in electrical engineering for the last two years. In the first year you do Physics, Chemistry, and Pure and Applied Mathematics. These subjects form the basis of all the future work, and the only subject you do not need to concentrate on too much is Chemistry. In the second year you do Mathematics, Surveying, and an introduction to Electrical Engineering which is called Electrical Technology. There is quite a lot of work on Mechanical Engineering, which comes under two subjects, Heat Engines and the Theory of Machines. In Heat Engines they teach you the theory of how different engines work, petrol engines, diesel engines, steam engines, and so on. This is useful for the electrical engineer, because he may get a job in a power station where the generators are driven by steam turbines. It may be a great help to know something about the theory of the turbine, because then he can understand the difficulties that the mechanical engineer who looks after the turbines has. The Theory of Machines is about the design of machines, and is perhaps not so necessary for the electrical engineer. But he must get to know how to read engineering drawings and that is most essential in all types of engineering. Two other subjects the student learns in his second year are Hydraulics and Engineering Drawing. Engineering Drawing makes you learn to know what a piece of apparatus will be like after seeing a plan and an elevation. It is also very good practice for using drawing instruments, and it is useful for an engineer to be able to make neat, accurate plans when he has to. Hydraulics is about the behaviour of liquids under different conditions. The engineer who is working in a hydroelectric station can understand his job much better with a good knowledge of Hydraulics. The last two subjects are the Theory of Structures and Strength of Materials. The Theory of Structures is most useful for civil engineers who put up large buildings and bridges, but electrical engineers who are putting up pylons and substations must know a lot about structures. Strength of Materials is most important, because it deals with the behaviour of different materials under all possible conditions; for example, an electrical engineer will want to know how strong conductors and poles must be to stand up to a high wind, how strong insulators must be to bear the weight of the conductors, and many other similar things.

At the end of the second year the student starts specializing, and most of the subjects from then on are closely connected with electrical engineering. The subjects include the theory of radio, how measuring instruments work, and how electrical power is made and distributed. Mathematics is a subject that is always useful. In these days many scientific explanations rely on mathematics to make the explanations either shorter or more accurate. It is best to think of mathematics as another language, and to try to become fluent in it. As you learn more mathematics, so it becomes more interesting, and in trying to work out a difficult mathematical problem there is all the excitement of reading a good detective story, but at the end you have done something useful!

When you have finished the university course, you must have some experience of practical work. All engineering problems are practical problems in the end, and the engineer must understand how things are done in fact as well as on paper. For example, it is one engineering problem to design a large transformer, and it is another engineering problem to move that transformer to its site when it is built. A student who has done a university course will spend two years on his practical training. He must work hard during those two years to gain all the practical experience he can.

The second way of training is to work in a firm of electrical engineers for five years, learning the theory at evening classes. This is probably harder work than the first way, but the student has a wider practical experience at the end. The subjects that he learns are the same, but they are not treated in quite so much detail. One great advantage of the second method is that in these times it is rather cheaper. The university course costs a lot of money, and the student must also pay for his living. He can work in the holidays to earn some money, and many firms run courses in the summer specially for people who are studying at universities. On the whole, it is more expensive to take the university course; but it is a better course, because the student can get a wider picture of the engineering world and of the world in general.

If you think of becoming an electrical engineer, what are the subjects to study at school? The most important subject for an electrical engineer is Physics, and particularly Electricity and Magnetism. But a good general knowledge of Physics is most useful, as it forms a good basis for all future work. As I have said above, Mathematics is very important in these days. It is particularly useful if you want to do research, because many people use Mathematics to make their explanations of new things they have discovered shorter and more precise. If you have the chance, it is a good idea to get some practice using your hands. If you can learn to make little things soundly and accurately, it will give you an idea of doing the same things on a bigger scale. Whatever an engineer does there may be occasions when simple practical experience makes all the difference to finishing a job in time. So the three things to concentrate on at school are Physics, Mathematics, and practical workshop experience, if possible. But don't forget wide reading and practice in writing, because engineers these days have to do much talking and writing. You don't want to find that you have got a wonderful idea but you can't get anyone to accept it because you can't explain it!

## THE CARBON CLOCK

The Earth is bombarded by rays from space called "cosmic rays". One effect of these atom-splitting rays is to convert carbon atoms in the carbon dioxide of the Earth's atmosphere into radio-active carbon atoms called "radio-carbon". The atomic weight of ordinary carbon is 12 and that of radio-carbon is 14, but both forms of carbon are chemically the same. The result is that all carbon compounds above ground level contain a fixed (though small) proportion of radio-carbon.

Radio-carbon atoms eventually revert to ordinary carbon. A gram of pure radio-carbon would contain about ½ gm. of ordinary carbon after 5,500 years, and about ¾ gm. after 11,000 years. Since radio-carbon is radioactive, though only feebly, it is possible to measure very small quantities of it. When living material containing carbon dies and is buried, the proportion of radio-carbon gradually decreases. Using these facts scientists are able to estimate the age of materials containing carbon, e.g. wood, cloth, food grains, bones, and so on, which may be discovered in prehistoric sites found by archaeologists.

# The Days of the Week

### O. B. TYMMS

It is always interesting when we read of some event in the past to know not only the date upon which it occurred, but also the day of the week, but unfortunately we are not usually told this. Thus we know that the Battle of Blenheim was fought on August 13th, 1704, but we are not usually told what day of the week this was. We are going now to consider two methods for finding this out.

We must first see what difficulties arise. Our year is the time taken by the Earth to pass round the sun and our day is the time taken for the Earth to rotate about its own axis. Unfortunately the day does not exactly divide into the year and we have the awkward fact that there are 365.242216 days in a year. The difficulties of the calendar are mostly due to mistakes which were made in adjusting these two figures.

The first attempt to obtain a really accurate calendar was made by Julius Caesar, who took a year as $365\frac{1}{4}$ days, which is about 10 minutes too much. The extra quarter of a day was used every fourth year to make a leap year. This was known as the Julian calendar and was in use until 1582. By then the 10 minutes for each year had added up to about 10 days and Pope Gregory XIII set about putting things right. He had to do two things, first to get rid of the 10 days and then to alter the calendar so that it didn't occur again. The first was easy. He merely had to announce that March 1st, 1582, was nothing of the sort and that it was really March 11th, 1582, but for the second he had to rule that in future the last year of each century should not be a leap year unless the number of the century were divisible by 4. Thus 1700, 1800, 1900, 2100 are not leap years but 2000 is. This reduces the error each year from over 10 minutes to less than half a minute and means that we shall not be wrong by as much as 1 day before the year 5000, by which time no doubt we shall have some new calendar. This second revision is called the Gregorian calendar.

However, although the Pope was very important and powerful, he could not compel Protestant countries to adopt his new calendar. It was accepted very reluctantly some time later by most countries. This country waited nearly 200 years, until 1752, by which time the error was 11 days, before the change was officially made and even then there was a great deal of trouble because people thought they had lost 11 days' pay! Greece was even slower and only made the change in the last few years—until then both calendars had been in regular use.

TABLE I.—THE NUMBER OF THE MONTH

| *Month* | M | *Month* | M |
|---|---|---|---|
| January | 1 | July | 6 |
| February | 4 | August | 2 |
| March | 3 | September | 5 |
| April | 6 | October | 0 |
| May | 1 | November | 3 |
| June | 4 | December | 5 |

A German, Karl Gauss (1777–1855), who was a great mathematician, gave the simplest method of solving our problem. He shows that W, the day of the week (starting with Sunday = 1), is found by adding together

D, M, C, and Y, then dividing by 7 and using the remainder only. D is the day of the month, M depends on the month and is given in Table 1, C depends on the century and is given in Table 2. Y depends on the last two digits of the year and is given in Table 3. There

TABLE 2—THE NUMBER OF THE CENTURY

| *Gregorian Calendar* | | *Julian Calendar* | |
|---|---|---|---|
| *Century* | C | *Century* | C |
| 15, 19, 23 | 1 | 00, 07, 14 | 5 |
| 16, 20, 24 | 0 | 01, 08, 15 | 4 |
| 17, 21, 25 | 5 | 02, 09, 16 | 3 |
| 18, 22, 26 | 3 | 03, 10, 17 | 2 |
| | | 04, 11, 18 | 1 |
| | | 05, 12, 19 | 0 |
| | | 06, 13, 20 | 6 |

TABLE 3.—THE NUMBER OF THE YEAR

Y

| 0 | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 00 | 01 | 02 | 03 | — | 04 | 05 |
| 06 | 07 | — | 08 | 09 | 10 | 11 |
| — | 12 | 13 | 14 | 15 | — | 16 |
| 17 | 18 | 19 | — | 20 | 21 | 22 |
| 23 | — | 24 | 25 | 26 | 27 | — |
| 28 | 29 | 30 | 31 | — | 32 | 33 |
| 34 | 35 | — | 36 | 37 | 38 | 39 |
| — | 40 | 41 | 42 | 43 | — | 44 |
| 45 | 46 | 47 | — | 48 | 49 | 50 |
| 51 | — | 52 | 53 | 54 | 55 | — |
| 56 | 57 | 58 | 59 | — | 60 | 61 |
| 62 | 63 | — | 64 | 65 | 66 | 67 |
| — | 68 | 69 | 70 | 71 | — | 72 |
| 73 | 74 | 75 | — | 76 | 77 | 78 |
| 79 | — | 80 | 81 | 82 | 83 | — |
| 84 | 85 | 86 | 87 | — | 88 | 89 |
| 90 | 91 | — | 92 | 93 | 94 | 95 |
| — | 96 | 97 | 98 | 99 | — | — |

are two words of warning. First, we must watch which calendar we are using, especially if the date is near 1582; secondly, if the month is January or February we must diminish the number of the year by 1. This is done to make February 29th, when it occurs, the last day of the year. Now let us test out the day of the Battle of Blenheim. D, the day of the month, is 13, M from Table 1 is 2 for August, C from Table 2 is 2 because we are using the Julian calendar. (In England, the Gregorian calendar did not come into use until 1752.) Y from Table 3 is 5. Then $D+M+C+Y=13+2+2+5=22$. The remainder when we divide by 7 is 1, so we know the battle took place on a Sunday.

Another method is to use the Perpetual Calendar. You only need then to be able to draw tangents and parallel lines. There are four steps in the process needed.

1. Find the date and the month on the outer ring. If these are separate, draw a line joining them; if they are the same point, draw a tangent to the outer circle at that point.
2. Find the century on the middle ring and through this point draw a line parallel to the line already drawn. This will either be a tangent to the middle ring or it will cut this middle ring again at another point on a radius. This new point (or the same one if it was a tangent) is the one we now want.
3. From this point follow the radius to the inner ring. Then find the year on the inner ring. (If the month is January or February diminish the year by one.) Draw a line through these two points on the inner ring; if they are the same point, draw a tangent. (If both points are on the Saturday radius, that is the day required.)

4. Now draw a line parallel to the one we have just drawn through the point where the Saturday radius meets the inner circle. The two lines may coincide. In any case the other point where it cuts the inner circle is the day required.

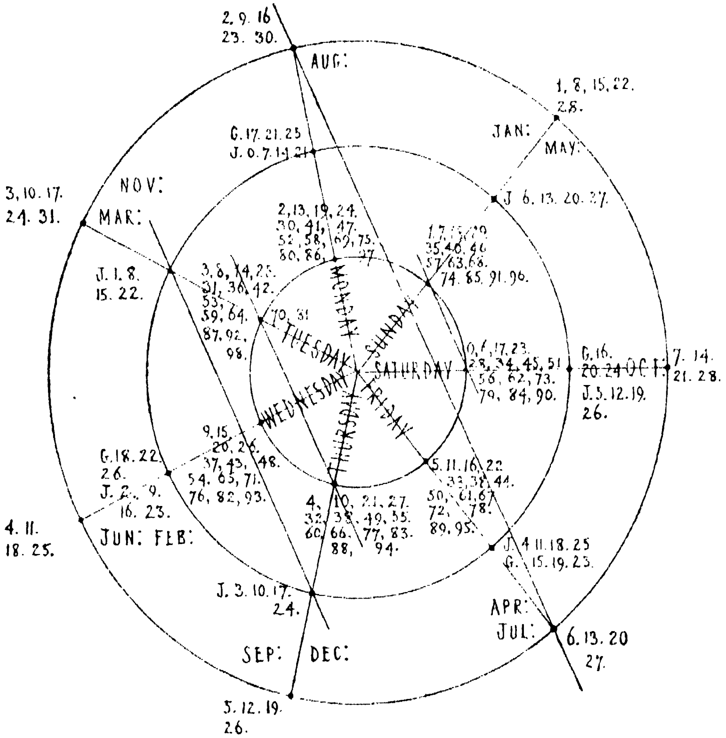


Fig. 1. Perpetual calendar.

We have drawn in the appropriate lines for August 13th, 1704, and this again provides us with Sunday as the day of the week.

At first it may be necessary to draw in the lines, but with a little practice it should be possible to judge by eye.

# Sitting on a Pin

A. C. FITT

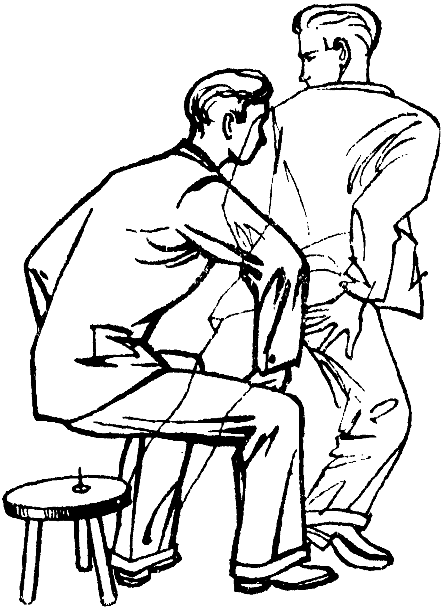


Fig. 1. Sitting on a pin (and jumping off).

No doubt most of you at some time or other have had the unfortunate and somewhat painful experience of sitting on a drawing-pin or some other sharp object without realizing that you were about to do so. In fact many of you have probably been pricked with a pin in the nether regions by a friend with a warped sense of humour. If you cast your mind back and try to remember your actions (or "reactions" as they are called by the scientist) on these occasions, you can perhaps remember jumping into the air, waving your arms about, and giving a yell. However, if you think a little more carefully you will perhaps have a recollection of jumping before you felt any pain or made any remark at all. Let us see why this should be so.

The fact that you moved before you were conscious of any pain was because the act of jumping away from an unexpected pin-prick is what is called a "reflex action". A reflex action is an action which takes place without orders, so to speak, from the brain. Most of our movements involve some form of thought; for example, if you find it necessary to lay the fire and light it, a series of carefully thought-out actions follows. You must fetch the coal, the wood, the paper, place the paper in the grate, then the sticks arranged carefully on top, and then the coal on top of them. Finally a match must be applied. All these actions involve conscious thought. In this they differ from reflex actions which literally take place without any thought at all. Reflex actions are often, but not always, protective. In this case, for example, the immediate result of sitting on a pin is to jump away from it. Your immediate reaction to a cricket ball thrown at your head is to "duck". If you pick up a hot object you drop it before you feel any pain. A reflex action which is not protective in function is that of your mouth watering when you smell the dinner cooking. In this case your digestive system is getting ready to deal with the food you hope and expect to get!

Before examining in detail what happens when a reflex action takes place, let us consider what obvious actions take place. The most obvious one is that of rapid movement. Now any movement involves the contractions of muscles. The next point to consider is what causes these muscles to contract. The answer is that they are worked by nerves. Perhaps this can be more clearly understood if for the moment we regard a muscle as an electric bell. An electric bell placed to a table by itself, however long it is left there, will not ring; but if two wires are attached to the terminals and an electric current is passed, then the bell will ring. In this case the electric bell is the muscle and the nerve represents the wires and the battery. During a muscular contraction an exactly similar thing happens; a nervous impulse or message passes down the nerve to the muscle and causes it to contract, in other words, rings the bell. If no message is passed, or if the nerve to the muscle is cut, then there is no response by the muscle.

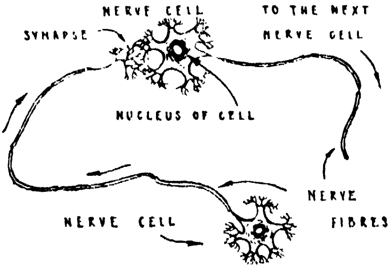


Fig. 2. The structure of nerve cells.

The nerves themselves appear to the naked eye like threads of white cotton, but under the microscope their wonderful structure is revealed. Each nerve, of which there are many hundreds in the human body, is made up of many nerve cells. As you see from the diagram, each cell consists of a cell body and a long projection called the fibre. The things we speak of as nerves are made up of thousands of nerve fibres, all bound together rather on the principle of an underground telephone cable which has many small wires inside it. The cell body is branched not unlike a tree. These branches lie very close to branches from other cells, and thus messages can be passed from one cell to another and all the nerve cells in the body are kept in communication with one another. Some idea of the amazing structure of these nerve cells can be obtained when it is said that although the cell bodies can only be seen under a high-powered microscope the fibre may be several feet in length!

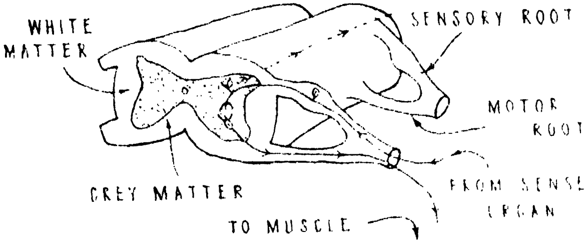


Fig. 3. Section of a spinal cord showing path of impulse in a reflex action.

These nerves are not scattered about the body in a haphazard manner but are arranged in a definite pattern, which is the same in all human beings. Some of the nerves make up the brain, some form the spinal cord, while others form branches from both the brain and the spinal cord to the various muscles and organs of the body. It is the spinal cord and the branches from it which chiefly concern us in considering what takes place during a reflex action.

The spinal cord itself is divided into two distinct areas. In the centre is what is called the "grey matter", which consists mainly of cell bodies. Surrounding this is the "white matter", consisting of nerve fibres running to and from the brain. All the cell bodies of these fibres are in the white matter. In addition, the remainder of the grey matter is made up of cell bodies whose fibres form what are called "lateral" nerves. These are branch nerves which come from the spinal cord at intervals all along its length as it runs down the back. These lateral nerves always come off the spinal cord in pairs, one on each side. Each nerve of the pair has a particular function. One, called the "sensory" nerve, carries the message from the sense organ (that is to say from the eye, the ear, the skin, and so on depending upon which of our senses is involved) to the spinal cord. The other, called the "motor" nerve, carries the message from the spinal cord to the muscle. But, you may ask, how does the message pass from one nerve to the other, and what is the message anyway? To the first question a fairly straightforward answer can be given. This is where the grey matter in the spinal cord comes into the picture. You will remember that it is composed of cell bodies some of whose fibres make up the lateral nerves while others communicate with the brain. We have also seen that these cell bodies are much branched and that through these branches nerves are in communication with each other. So the grey matter acts like a local telephone exchange. The message arrives by way of the sensory nerve and passes into the centre of the cord. Here it passes through various cell bodies and their branches until the "correct number", as it were, is reached, and off it rushes down the motor nerve and works the muscle. The answer to our second question is not so simple. All that can be said is that nervous messages are apparently electrical because minute electrical currents can be picked up in a nerve which is being used to pass messages.

Having now discovered the "set-up" of the nervous system we can trace what happens when we sit on a pin. First of all the prick is felt by the nerves in the skin of that area, the message is passed into the nearest sensory nerve and thus reaches the spinal cord. Here it passes by way of various cell bodies and their branches to the motor nerve which works the leg muscles, with the result that you leap to your feet. All this takes place in a flash. Exactly how quickly may be understood when it is said that messages travel along nerves at about the speed of a revolver bullet.

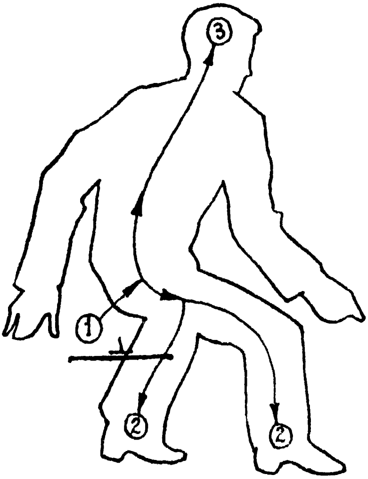


Fig. 4. Sensory and motor nerves: (1) pin-prick to spinal cord; (2) message to leg muscles; (3) message to brain to carry pain.

As you know, after you have leapt into the air you realize what has taken place. This is because a message is also sent to the brain by way of the fibres in the white matter, and so your intelligence comes into play. For this reason it is sometimes possible to resist the working of a reflex action. Suppose you pick up a very hot vegetable dish which burns you. Your natural reflex action would be to drop it. However, in a case of this kind most people, quick as a flash, think "I must hang on", and do so until they find a safe resting place for the dish.

We have now seen that quite a number of our everyday actions can take place without thought, at any rate, in the first instance. But if you consider this more deeply you will realize that a number of actions you perform take place without any thought at all. For example, we all walk quite easily and without thinking about it, but as you know, we all had to learn to walk in our babyhood, although we cannot remember doing so. However, you may only too well remember learning to cycle, often no doubt with very painful results. You may also remember learning to write. All these actions are what are known as "conditioned reflexes". They are actions which due to constant repetition take place without any thought. Swimming is another example of this type of reflex action. Once you have learnt to swim you do not have to think what to do when you dive into the water; you just swim, so to speak, instinctively.

In addition to reflex actions there are a number of movements taking place in the body which go on day and night so long as we are alive. Examples of these are the beating of the heart, the movements which enable us to breathe, and the movements of the stomach and intestines in digesting food. I think we would all agree that we have no part in controlling these at all; at any rate no conscious part. Well, how is this done?

Besides the nervous system consisting of the brain and spinal cord together with its nerves, there is another complete nervous system which controls all these automatic actions. It is called the "sympathetic nervous system". This arises directly from the brain as two "sympathetic" nerve cords which run down on each side of the backbone. From the cords run off nerves to all the internal organs of the body. These sympathetic nerve cords are also connected to the nerves running to and from the spinal cord. This sympathetic nervous system is responsible for all essential movements which take place in our internal organs and to which we give no thought. However, it does more than this; it prepares our body for any emergency. We have all had to face some emergency in our time! We have all experienced "that sinking feeling". This may be brought on by waiting to bat at a critical moment in a cricket match, by entering the room for an important examination; it has even been known to come on when awaiting an unpleasant interview with someone in authority! What is that "sinking feeling"? If we analyse it I think we shall agree that its usual form is a nasty feeling in the stomach and a great increase in the rate of beating of the heart. All this is caused by the sympathetic nervous system. In an emergency it almost completely suspends the movements of the

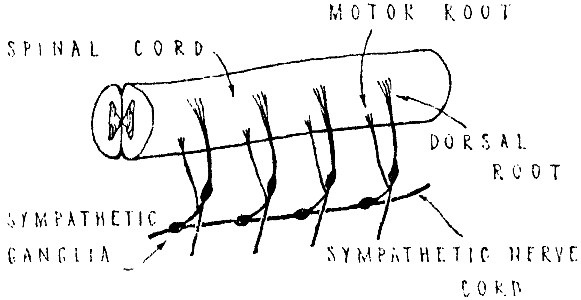


Fig. 5. Relationship of sympathetic nerve cord to spinal cord.

stomach and intestines—hence the nasty feeling in the stomach. Secondly, it increases the rate of beating of the heart in order that more oxygen should be carried round the body to the muscles so that we shall be ready for a great physical effort.

After the emergency is over there is usually a feeling of complete relaxation. This is brought on by yet another system of nerves called the "parasympathetic nervous system". This is made up of a system of nerves running directly off the brain to all the organs of the body and it works in complete opposition to the sympathetic system. That is to say, it slows down the heart beats and starts up the movements of the intestines again, and in doing so it causes that weak feeling at the knees!

So we can see that, although we may like to think that we have complete control over our bodies, this is in fact far from being the case. Our bodies are, of course, under control, but to a great extent this control is not achieved consciously by us but is entirely unconscious. And, after all, this is not a bad arrangement. It would be very tiresome if you had continually to remember to keep your heart beating, and your lungs breathing, and to digest that doughnut you had ten minutes ago. And next time you sit on a pin, comfort yourself with the thought that your reflex action of jumping and yelling has possibly saved you from more serious hurt.

*INSTRUMENTS OF SCIENCE II*

# Calculating Machines and Mathematical Instruments

J. R. A. PEARSON

It is always best when speaking of any machine or instrument to think first of what can be done with it, rather than of how it is constructed. You will find such a simple outlook very helpful whenever you are trying to understand a particularly complicated machine. Once you have realized what is being done, you will find the details of the particular machine much easier to understand. Fortunately, nearly all calculating machines have been designed to do the same basic job, that is, to carry out mechanically the elementary arithmetic operations of addition, subtraction, multiplication, and division. So you see, the principle involved is very elementary, and I hope to make the details of particular instruments as simple as possible.

I will begin by giving you a very simple example of what I mean by a basic process. Consider the ordinary 12-inch ruler or scale. When you measure a length, you always give your answer in terms of some unit (for example the inch), and measurement is essentially a question of finding out how many of these separate units (or inches) will make up the length when put end to end. The ruler is intended to do one part of the process for you; it puts the inches end to end and so tells you what one, two, three, up to twelve inches look like. You may think it silly to call a ruler an instrument, because it is no more than a piece of wood or steel marked off at regular intervals, but as we go along you will realize that it is the first of a series of instruments used to facilitate calculations. At this point I want to introduce you to digital machines and to distinguish between digital machines and others, so that there will be no difficulty later. Digital machines deal with discrete numbers, that is to say, with whole numbers, or in special cases with certain fractions of whole numbers. They perform by a series of jumps, rather like a taximeter. What distinguishes digital machines from others is that they measure only numbers and relations between numbers. Of the other types of machines I will only say that they include instruments which can be used to measure quantities other than number, such as length, area, or angle. The example given above is an illustration of a non-digital machine, for a ruler measures length directly. When I come to describe the various types of calculating machines I will explain first the many types of digital machines which are nowadays the more important.

Whether we regard the process of civilization as due to man's idle nature or to some inherent desire for improvement, we find that the development of calculating machines has provided a means of lightening the burden of mental arithmetic. In fact the chief reason behind this development has been the desire to make the process of calculation easier, quicker, and less liable to error. First of all came the need for counting money and the adding together of several amounts, the problem which faces the shop assistant today. This need led to the invention of a series of digital machines, always very simple to operate, which are now familiar as the cash-registers which automatically add up the day's takings, which are used in many shops. When money came to be used and to be borrowed and lent, a rate of interest was charged for it. This involves a simple calculation which you yourself have carried out many times no doubt. Now these calculations have one important point in common: the same simple operation is repeated many times. For example, if the rate of interest is 3% per annum, then the money-lender requires £3 interest every year for every £100 he has lent, and so a machine which gives 3/100 of any sum of money would be of great help to him in working out how much he was owed. Again this is a very simple example, and you might feel that it would be easier to work it out on a sheet of paper. But suppose that there were hundreds of these sums and the rate of interest was 3¾% per annum. Then you might appreciate such a machine. The growth of civilization also gave rise to other arithmetical calculations, such as those concerned with the measurement of area or of angles and distances between heavenly bodies like the sun and the stars.

Now I want to jump ahead a little and mention the more complicated problems which mathematicians have to solve. Some of you may have come across quadratic equations and have been introduced to the formula $\frac{1}{2a}\left\{-b\pm(b^2-4ac)^{\frac{1}{2}}\right\}$. This is, of course, a simple example; there are in fact many such formulae, usually very much more complicated, which mathematicians, engineers, and scientists have to evaluate for a great number of values for each variable—in the case given, for different values of $a$, $b$, and $c$. Now a machine which could carry out the operations shown above on any three numbers would be a great advance, and so we have a series of instruments which have been specially designed to perform such operations. But I do not want you to worry about complicated calculations, because one remarkable fact has emerged—that the easiest way to do even the most difficult calculations is to break them down into the elementary operations I mentioned at the start—in fact, into one only of those operations, namely addition. Hence we find that the earliest problem, that of mechanical addition, has remained fundamental, and that better and quicker ways of mechanical addition have meant better machines for all purposes.

The first calculating machine I shall consider is the abacus, which was used by the Egyptians, Greeks, and Romans in early times, and which is still used in China. The abacus is best understood by looking at the diagrams on the next page. These represent a frame holding in place parallel wires on which are threaded sets of ten beads. The extreme right-hand column represents units, the next tens, and the left-hand column hundreds.

In Fig. 1 a number, 623, is set up by bringing down the requisite number of counters in each column. In Fig. 2 is shown the result of adding 34 to 623 on the abacus. The only process to be explained is that of carrying over. If all ten counters have been brought down in one column, then they are all thrown up again, and one in the next column on the left is brought down instead. This merely says that $10 \times 1 = 10$, or that $10 \times 10 = 100$. Thus this machine took the place of mental arithmetic and even multiplication was carried out by means of repeated addition, a process I will explain later. But I want you to understand very well what I have said above before you go on, because it is important. As a means of representation, you are accustomed to writing "six hundred and twenty-three" (or "six hundreds, two tens, and three units") as 623, and you are familiar with carrying over, so that forty-nine added to fifty-three gives nine tens plus twelve

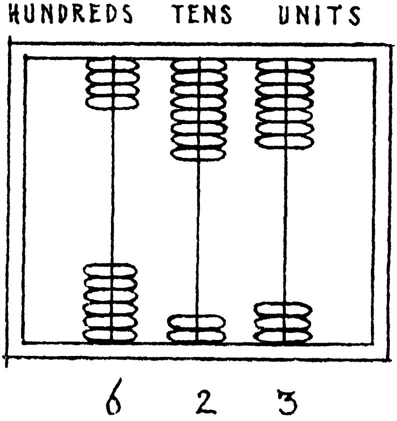


Fig. 1. The number 623 on the abacus.

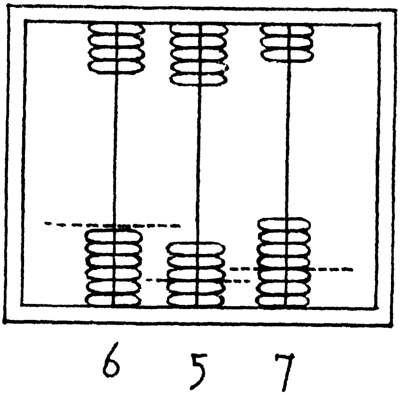


Fig. 2. The number 34 added to 623.

units, or ten tens plus two units, or one hundred, no tens, and two units. In figures, $49+53=102$. That is just the way in which the abacus works, and also the way in which all the later adding machines work. Now perhaps I can make clear what I mean by multiplication treated as repeated addition. The five times table tells you that five times nine is forty-five; I could say the same thing in figures, thus: $9+9+9+9+9=45$. This is in fact the only way of working out $5\times9$ on an abacus. You will agree that $5\times9$ is merely a shorthand way of writing $9+9+9+9+9$, and therefore that multiplication is repeated addition. If you start to write out $427\times539$ in full, you will realize how useful this shorthand can be.

The next mechanical aid to arithmetic depended on the use of the multiplication tables and was commonly known as Napier's rods, or Napier's bones. These were regarded as invaluable when they first appeared in England in 1617. A detailed description of them would not be very enlightening, although they were often beautiful examples of craftsmanship in ivory or rare woods. Two simple diagrams will serve to make clear their main purpose. Each rod represents the multiplication table for any chosen unit from one to nine, the diagonal lines serving to separate the units from the tens. Fig. 3 shows the table for 3, and how the bones are fitted together. By putting the numbers shown at the top of the rods side by side, we obtain the multiplication table up to nine for any composite number; the only difficulty in reading off the result is that for each figure in the answer, an addition has to be performed. In Fig. 4 is shown $6\times3591$, one process of carrying over being necessary in this example. Napier's bones could be used for a great number of different calculations, but they really only eliminated the effort of mental multiplication of single units which you have to do when you write down:

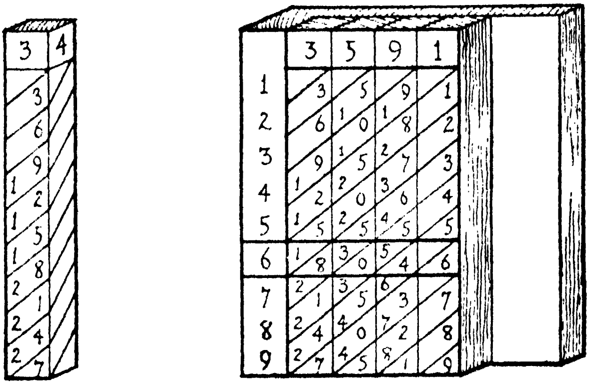


Fig. 3. Napier's "bones" for 3; an assembly of bones.

6 X 3591 IS GIVEN BY
0 + 6 = 6 UNITS
0 + 4 = 4 TENS
5 + 0 = 5 HUNDREDS
3 + 8 = 11 THOUSANDS
1 + 0 = 1 TEN THOU:
TOTAL 21546

Fig. 4. The use of Napier's bones. (See Fig. 3).

$$\begin{array}{r}3591\\6\\\hline 21546\\\hline\end{array}$$

The seventeenth century also saw the first mechanical calculating machine. This was invented in 1642 by the Frenchman Blaise Pascal, who later became an eminent mathematician. His father's work involved a great deal of arithmetic, so that, in this case, necessity was truly the mother of invention. I want you to follow the description of the principle involved very carefully, because once you have grasped it you will have no real difficulty in understanding any of the later models. A photograph of an early machine is included so that you can see how it appeared to the operator; but here only the principle involved will be explained.

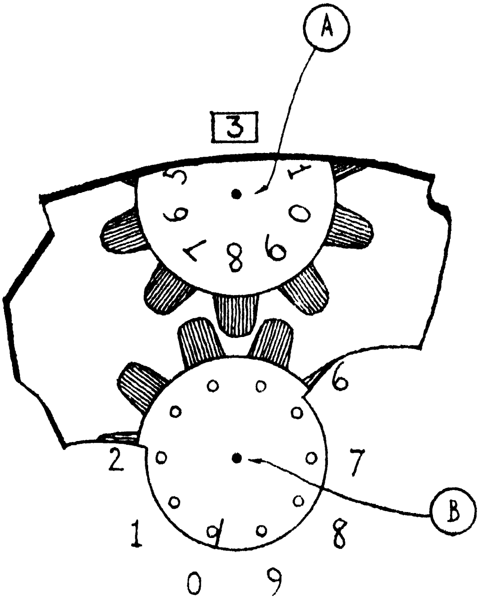


Fig. 5. The gears of a digital machine.

In Fig. 5 you see a pair of cog wheels or gears. The upper cog bears the numbers 0 to 9 spaced around it at regular intervals; these are the numbers which the operator sees through the hole in the case, and obviously only one number is visible at any one time. The lower cog has ten holes which coincide with ten figures spaced evenly round a circle marked on the case. Now the numbers of teeth on each cog are so chosen (in this example the numbers are equal) that if one of the holes in the lower cog is moved round one place, then the number seen through the hole changes by one. In operation a pointer is placed in the hole opposite the number required and the wheel is turned in a given direction (in this case anticlockwise) until the pointer appears opposite the number zero. The required number is then found to have been added to the number previously showing in the hole above. If I take a very

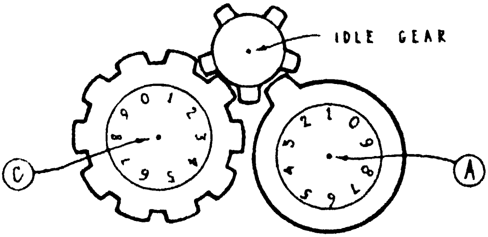


Fig. 6. The method of "carrying one".

simple example, that of adding 4 to 5, all I do is to put the pointer into the hole opposite 5 and turn, when the number 5 will appear; then put the pointer into the hole opposite 4, turn again, when the number 9 will appear. The machine has therefore added 4 to 5 correctly. Now you will already have seen a difficulty; what happens when we add 1 to 9? We should get 10, but on this wheel only zero is shown. The answer is that the cog on the left moves round one place. The upper cog A has, in addition to the main gearing to B, a single tooth which can engage through an idle gear with the next upper wheel C as C turns through 1/10 of a revolution for each complete revolution of A (Fig. 6).

Thus, as A changes from 9 to 0, so C increases by 1. Now, by putting a series of these pairs of wheels side by side, we can show units, tens, hundreds, thousands, and so on as far as we like. So far I have mentioned only addition; obviously we can subtract by reversing the direction of rotation, and, as you may have guessed, most adding machines can be used for subtraction also. At the end of each sum the numbers have to be cleared; that is, all the numbers showing must be brought back to zero. That is done with the pointer and the machine is then ready for the next sum. A slight alteration to the basic design gives a machine for adding pounds, shillings, and pence. Instead of going from 0 to 9, the right-hand wheel goes from 0 to 3 (farthings), the next from 0 to 11 (pence), the third from 0 to 19 (shillings). The fourth, fifth, etc., would show pounds. This is easy to understand, since each fourth farthing would register one penny and so on. Similarly a machine may be built for adding ounces, pounds, and stones, or seconds, minutes, and hours.

The next important development led to the more elaborate and versatile multiplying machines. These involved several elaborations of the mechanical principles used in the earlier ones. First came a device for setting up numbers, together with a handle-operated shaft which, on turning, completed the addition of a many-digit number. Consider, instead of the lower wheel in Fig. 5, the wheel shown in Fig. 7. A lever which can be moved so as to be brought opposite any of the ten digits on its own scale releases a series of rods which protrude from the wheel and so act as teeth. Thus, if on the lever scale which has replaced the lower wheel in Pascal's machine, we set up any number, we set up a corresponding number of teeth on the appropriate wheels. Suppose that we now turn the wheels simultaneously through a complete revolution by means of a handle at the side of the machine, then we are adding the number set up on the lever scale to the number already shown on the answer scale. So far I have only given you a rough idea of the change in principle. The design was altered too; the answer scale was moved to the bottom of the machine, while the wheels or cogs were all turned on their sides so that they lay closer together, thus allowing the numbers to be read more easily. The carrying-over operation was so arranged as to occur only when the main addition operation had been completed. The second innovation was directly connected with multiplication. One set of wheels was made movable (in a transverse direction) so that any particular wheel on the lever scale could be brought opposite any one of the wheels on the same scale.

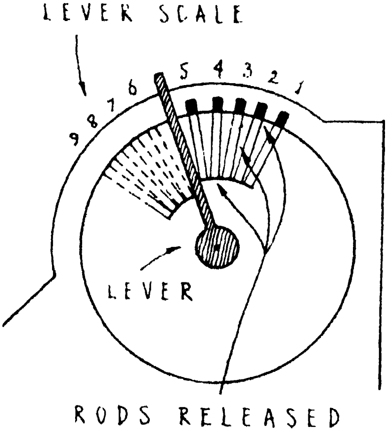


Fig. 7. The lever scale.

Hence the number set up can be multiplied by *10*, *100*, 1000, etc., or by 1/10, 1/100, 1/1000, etc., at will. The multiplication of any many-digit number can now be carried out mechanically. Suppose that we have to multiply 1734 × 429. We set up the number 1734 on the lever scale and put the lever-scale units opposite the answer-scale hundreds. If we turn the handle four times, then 1734 × 400 appears on the answer scale. Move the movable scale down one so that units of the lever scale appear opposite tens on the answer scale. Turn the handle twice; we have added 20 × 1734 to 400 × 1734. Finally move down again and turn the handle nine times. We now have the whole product and the multiplication has been carried out. Two other improvements must be mentioned. One consists of a separate scale operated by the handle, showing the number of revolutions turned by the handle. Thus, in the example given, the figure 4 would appear on the hundreds wheel of this scale as the handle was turned four times, and so on until 429 had been registered. This is easily achieved by having a single tooth on the rotating shaft to which all the lever scale wheels are fixed; this single tooth meshes in turn with the teeth of each of the handle scale wheels. The other improvement is a clearing device fitted to each scale which brings the readings back to zero. By having three independent clearing devices a sum of products can be evaluated. The handle scale and the lever scale are returned to zero after each product has been obtained, but not the answer scale, so that a sum of products is registered on it. By retaining the capacity for working backwards (that is, reversing the direction in which the handle is turned), we include in one machine the mechanism for carrying out addition, subtraction, multiplication, and division—here we treat division as the reverse of multiplication. This is not a detailed description of any particular hand-operated calculating machine, but the main principle involved in all of them has been described. The photograph facing page 119 is typical of them all.

This very workable design had been developed commercially by the end of the last century, and the name most intimately connected with it is that of a German firm, Brunsviga. A patent was taken out in 1891. The last fifty years have seen two further changes, both of which involve ideas mechanically too detailed for this article. One is key setting, to take the place of the levers in the Brunsviga machine, sometimes combined with automatic carriage shifting; this greatly reduces the operating time. The other is the introduction of machines operated electrically. In the latest models the entire operation is push-button or key controlled, and the same block of keys is used for multiplicand and multiplier. There are of course no handles to turn, and no clearing levers. Even automatic division is possible. But once again I must emphasize that these are fundamentally the same as the Brunsviga machine described above. The power-operated variety are the calculating machines best known and most widely used today; they are to be seen in banks, offices, factories, and laboratories.

We have now come to the end of our discussion of digital machines. You have seen that they are simple to operate, and that they cover a wide field of application. They represent the mechanization of arithmetic, and have become one of the important tools of science in general.

There are, however, calculating instruments and machines of a different type. One type is connected with a development of mathematics which may be familiar to you; namely, logarithms and the logarithmic scale. This allows of multiplication by the addition of indices, and is done mechanically on a slide rule. This is today a widely favoured mechanical aid to mental arithmetic, although it is limited to multiplication and division. The other type includes a wealth of gadgets, some very ingenious, designed for particular purposes. Of these, one of the most outstanding is the planimeter, which gives an accurate reading of the area enclosed by any given plane curve or figure. It is operated by running a wheel fitted to the end of a bar around the enclosing line. There are certain other measurements which also have to be made, but these are not included for the sake of simplicity. The number of turns made by the wheel gives a reading for the area. The instrument itself is very simple; a bar of known length has a wheel perpendicular to it at one end, and rests on a curved knife-edge at the other. If we roll the bar on the wheel, using the knife-edge as pivot, we sweep out a circular sector, the area of which you may know is proportional to the length of the circular arc. Hence we have converted an area into a length which we measure in terms of revolutions of a wheel (Fig. 8). If we pull the bar along parallel to itself and to the knife-edge, the wheel does not turn, but neither is any area covered since the bar moves along a straight line. When we run the wheel round a closed curve, we are combining the two movements, and in this way we can measure the area inside the plane curve.

This little instrument has introduced you to a mechanical device which has been widely applied in some analytical machines, such as those used in calculating the speeds and heights of moving targets. Lengths or distances are represented by turns of a shaft or wheel, speeds by the rate of rotation of shafts, and accelerations by changes of these rates of rotation. The great advantage of this method is that rotations of shafts can be added or subtracted by means of gears. Numerous other devices allow of multiplication and similar operations. These enable us to build up relationships between various quantities, and hence to produce solutions of equations. This is but an outline of the principle involved, but it may help you to understand the idea behind the complicated arrays of gears and shafts which constitute certain modern analytical machines. These are essentially non-digital, because they deal with what are called "continuously variable quantities". I can explain this term quite easily. As any wheel turns once, the quantity it represents changes, for example, from zero to one. While it is turning, it assumes every value between zero and one; it does not proceed by a series of jumps, as I explained in describing digital machines. In recent years, however, the non-digital machines have become less popular, and are

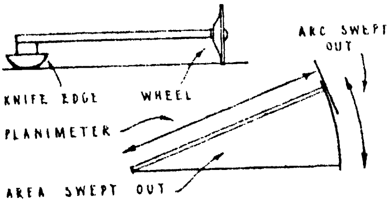


Fig. 8. The principle of the planimeter.

being replaced by electronic machines, of which I shall give a very brief account in the following paragraph.

We have been led at last to the latest and most refined of all calculating machines, the electronic computors, described by those who have vivid imaginations as "electronic brains". It is rather difficult to give you any more than a rough impression of the machines, so to start you off on firm ground, I will say that they work basically by addition, treating multiplication as repeated addition. But where they differ from the simpler versions I have already described is that, once they have been set to do them, they can perform consecutively a series of operations. They can also store a vast set of numbers, and use them as required—hence the suggestion that these machines have memories. As you need a knowledge of complicated electrical circuits to understand these machines, I cannot explain to you exactly how they work, but I can give you a simple example of what they can do. We may, for example, want to know the value of $n^2+5n-1$ for different values of $n$, say $n=0, 1, 2, \ldots$ up to 10. We feed in:

(i) the values 0, 1, 2, . . . to 10;
(ii) the expression $n^2+5n-1$, broken down into $n$ additions of $n$, plus 5 additions of $n$, minus 1;
(iii) an instruction to the machine to perform the operation (ii) upon the values in (i) in turn:

and we get a tabulated answer of the values.

In practice the machine is operated by typing out values and instructions which appear as holes punched in a paper tape. These are fed into the machine, where they are "read". (The use of the word "read" is another example of the way in which the machine is compared with a brain.) In effect the holes in the tape cause certain changes to take place in the machine, changes which correspond to the operations described. The machine obeys the instructions, and the answer appears as a set of figures typed out on a sheet of paper. To see this being done is an astonishing sight, and perhaps explains why these machines have been called brains. But do not imagine that any such machine can solve anything which its inventor cannot, for it can do only what it is told to do; it cannot "think" for itself. Its great advantage lies in the fact that it can work out these problems at an incredible rate; where a dozen human computors using mechanical Brunsviga type machines would take a year to get a page of answers, the electronic computor may take no more than a few hours. This is why so much time and trouble has been and can be spent in making them; in the future, when we shall have an increasing number of calculations to carry out, we shall find these machines invaluable.

If you have found calculating machines sufficiently interesting to read about them as far as this, I have a suggestion to make: go, if you can, to the mathematical section of the Science Museum, South Kensington, London. Except for an electronic computor, which would occupy a room on its own, you will find there either the originals or models of all the types of machines that I have mentioned, and many more that I have not. Above all, you will get a much better idea than this article will give you of the way these machines developed along the lines I have tried to illustrate.

# Space Travel

## J. P. GRANTHAM

SPACE travel means, for most people, inter-planetary travel within our own solar system, and, as this article is to be based upon scientific evidence, we must confine ourselves to the question of inter-planetary travel. Using known techniques and the improvements in them that we are at liberty to expect, inter-planetary travel should be possible in the near future. It is impossible to predict when the first trip is likely to be made, for the expenditure of much money and effort will be required before that day arrives. Let us, therefore, forget about travel to other stars and vague dates, and begin by considering the type of motor that we should need in our space-ship.

In order to overcome the gravitational force of the Earth and the friction of the earth's atmosphere, a space-ship must be capable of very high speeds; once the craft has left the Earth's atmosphere, thrust must be obtained by some type of jet-propulsion motor which does not require oxygen from the surrounding atmosphere. The only kind of motor known at present which will meet all our requirements is the rocket motor. There are certain characteristics that are general to all rocket motors and it is upon a consideration of these characteristics that we must base our first investigation into the possibility of inter-planetary travel. If we neglect external forces (gravity, atmospheric resistance, etc.) and apply

Newton's third law of motion, we arrive at the following results:

Let $V$ = velocity of rocket at any moment
$v$ = exhaust velocity
$M$ = mass of rocket
$F$ = mass of fuel at take-off
$f$ = mass of fuel consumed up to the present

$$r = \frac{M+F}{M+F-f},$$

then $$V = v \,.\, \log_e (r)$$
or $$e^{V/v} = r.$$

When all the fuel is consumed, the rocket will have reached its maximum velocity and $r = (M+F)/M$. This special value of $r$ is called the *mass-ratio* of the rocket. The velocity required to overcome the gravitational and air friction forces and so get clear of a planet is called the *escape velocity* of the planet. The earth's escape velocity is 7·0 miles per sec., and the best fuels available today give exhaust velocities of about 3 miles per sec. These figures give us a mass-ratio of nearly 25, which is much too big to be practical. It is necessary to increase the exhaust velocity to about 6 miles per sec. if the mass-ratio is to be reasonable. Alternatively, a two-stage rocket may be used; such a rocket is really two rockets joined together at take-off. One rocket only is used for the take-off and the early stages of the flight and is jettisoned when its fuel is exhausted; the second rocket then takes over. By this means the effective mass-ratio is increased, for some of the dead weight is removed after take-off. Another advantage of this technique is that a rocket motor designed for use with low rocket velocities can be used for the first stage, and a motor designed for high-speed use for the second stage. Although all rocket motors are more efficient at high rocket speeds, some types are better than others at low speeds. If a two-stage rocket is used, present fuels would not have to be much improved before a space-ship becomes a practical possibility, as far as leaving the Earth is concerned. Further improvement will be necessary before it is possible to make a return trip to another planet or the Moon. The first experiment will almost certainly be some form of "circular tour" that does not include landing on another planet.

Having decided on the use of a rocket motor, and assuming that improved fuels will become available, the second question is that of landing on the target planet. If no atmosphere is present, retardation (to overcome the planet's gravity) must be provided by the rocket motor. If, however, there is an atmosphere, a method of using it to give the rocket a gradual retardation has been invented. The rocket is aimed so as to miss the planet itself but to graze the atmosphere; the combination of the planet's gravitation and the air resistance causes the rocket to move on an elliptical orbit around the planet. After one circuit of the planet, the rocket again enters the atmosphere and is further retarded, continuing its motion on a new and less eccentric elliptical orbit. Eventually, the whole orbit is inside the atmosphere and the rocket spirals in. The whole procedure is shown in Fig. 1. As the atmosphere will be rarefied at large distances from the planet, gradually becoming denser closer to the planet, the rocket will not be retarded so quickly that the passengers or the craft are damaged. The use of these braking ellipses should enable a landing to be made without the expenditure of any fuel. We see, therefore, that although the take-off from a planet with an atmosphere requires extra fuel, the landing is accomplished without fuel consumption.

We still have to consider the journey itself; its characteristics will vary, depending whether it is made between objects close to each other (such as the Earth and the Moon), or more distant objects (such as the Earth and another planet). In the case of close objects, the gravitational force of one or other of them is appreciable throughout the journey, the gravitational effect of the Sun being small in comparison. When the take-off is over and the rocket motor is stopped, the craft will gradually slow down under the influence of the Earth's gravitation until a point is reached where the Moon's gravitational force equals the Earth's. The craft will then accelerate towards the Moon. Clearly, there is no object in using up more fuel than is necessary to ensure that the craft just crosses this null point. In the case of a journey to another planet, the craft is driven completely clear of the Earth's gravitational field so that it becomes a temporary satellite of the Sun. The direction and speed of the craft when it leaves the Earth's influence are so arranged that the elliptical orbit taken

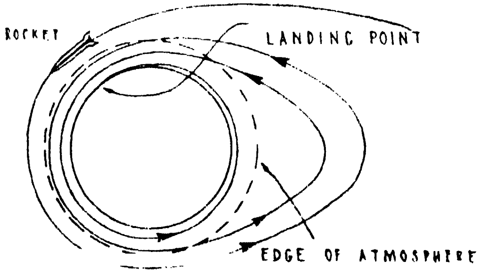
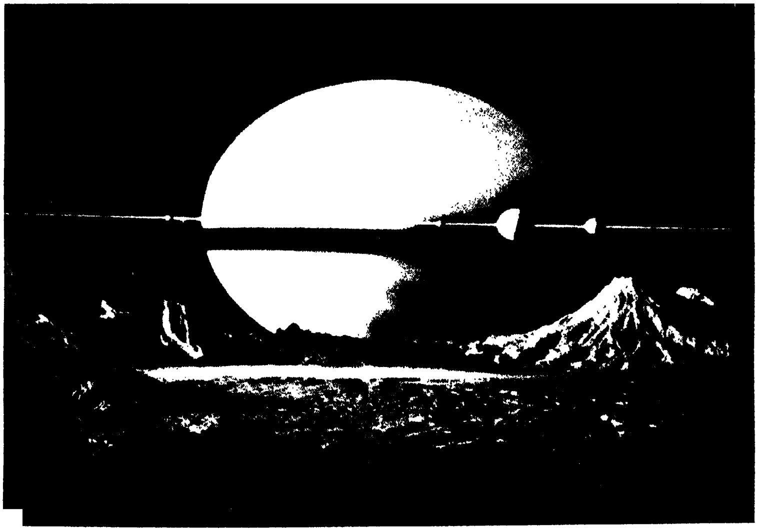


Fig. 1. Braking ellipses.

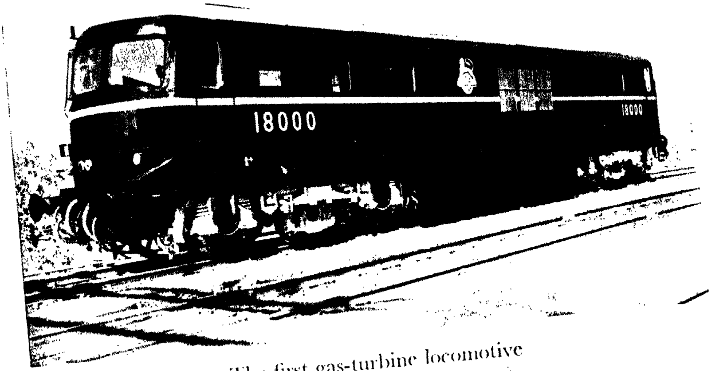
# PLATE IX. SPACE TRAVEL

Lunar landscape, showing Earth and the constellation of Orion as seen from the Moon

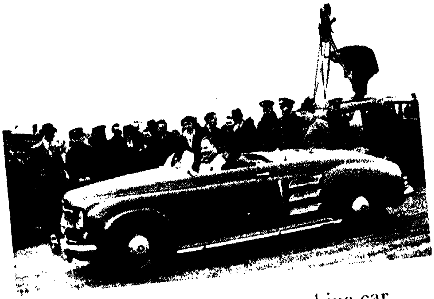


Saturn as it appears from one of its satellites. (*Both by courtesy of Messrs. Sidgwick and Jackson from* The Conquest of Space)

# PLATE X. GAS TURBINES



The first gas-turbine locomotive
*(By courtesy of British Railways)*



Rover experimental gas-turbine car
*(By courtesy of the Rover Company)*

up around the Sun grazes the orbit of the target planet. The timing is so arranged that the planet is at the desired place on its orbit when the craft arrives. In the last stages of the journey, the gravitational force of the planet will override the influence of the Sun, and our suggested course must be modified slightly to allow for this. If the craft leaves the Earth in the direction of the Earth's motion around the Sun, the craft's velocity around the Sun will be the sum of its own and the Earth's velocities. It will, therefore, travel on an orbit outside the Earth's. If the target planet lies on an orbit inside the Earth's orbit, the craft will be launched in the direction opposite to the Earth's motion around the Sun. An example, showing the path from the Earth to Venus is shown in Fig. 2.

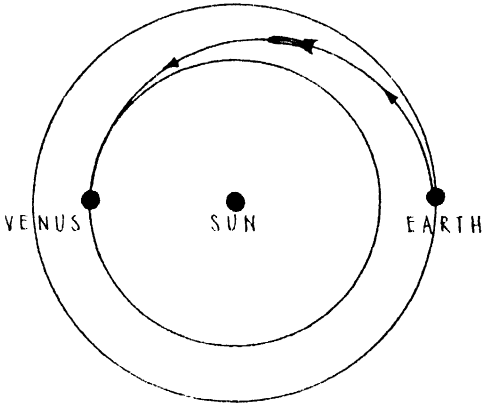


Fig. 2. Path of rocket from Earth to Venus.

A well-known liquid-fuelled rocket of comparatively recent design is the German V2. The rocket is 46 feet long, weighs 12½ tons at take-off, and carries fuel for a run of about 70 seconds under power. The mass-ratio is about 3 : 1, and the rocket can travel about 70 miles

## TABLE OF DATA ABOUT THE PLANETS FOR SPACE TRAVEL

| | Mean distance from sun ($10^6$ miles) | Length of year (Earth years) | Mass, compared to the earth | Atmosphere | Orbital speed (miles/sec.) | Escape velocity (miles/sec.) |
|---|---|---|---|---|---|---|
| Mercury | 36 | 0·24 | 0·04 | Very little | 30 | 2·2 |
| Venus | 67 | 0·61 | 0·8 | Dense | 22 | 6·3 |
| Earth | 93 | 1·0 | 1·0 | Normal | 19 | 7·0 |
| Mars | 142 | 1·88 | 0·11 | A little | 15 | 3·1 |
| Jupiter | 483 | 11·9 | 317 | Yes, probably dense. | 8·1 | 37 |
| Saturn | 886 | 29·5 | 95 | Yes, probably dense. | 6·0 | 22 |
| Uranus | 1783 | 84·0 | 15 | Yes, probably dense. | 4·2 | 13 |
| Neptune | 2794 | 165 | 17 | Yes, probably dense. | 3·4 | 14 |
| Pluto | 3675 | 248 | 0·7 | Not known | about 2·7 | about 6·5 |

away from the earth. A similar rocket, with the 1-ton "pay-load" (in this case the war-head) replaced by a second rocket so as to form a two-stage rocket, has been launched. The small second rocket reached a height of 250 miles and was much too small to be capable of carrying passengers; the point where the Earth's and Moon's gravitational fields are equal is about 200,000 miles from the Earth. However, we can take heart from the facts that at 250 miles the rocket was effectively clear of the Earth's atmosphere, and that at this distance the gravitational force of the Earth is already reduced to 88 per cent of that on the surface of the Earth.

In case you feel like calculating your chances of reaching a planet or the Moon, and want to know the size of rocket and motor you would need, I have drawn up a table giving the more important figures. In the case of planets with an atmosphere, you must allow a little extra fuel, for the fuel saved on landing by braking ellipses does not quite make up for the extra that you will need for the take-off. It is also advisable to remember that the climate on the surface of most of the planets is likely to be very unpleasant—even by English standards.

## CHANCE AND DISCOVERY

In his book "The Art of Scientific Investigation", Professor Beveridge describes more than thirty famous scientific discoveries that were made "by chance". The twitching of frog's legs noticed by Galvani led to the discovery of current electricity; the discovery of X-rays by Rontgen was accidental; the preparation of the first aniline dye by Perkin was due to an impurity in one of his reagents. There are many more examples of the part played by chance in scientific discovery, but, as Pasteur said, "Chance favours only the prepared mind".

# The Gas Turbine on Land and Sea and in the Air

C. G. CONWAY

THE gas turbine and jet propulsion are closely linked in the public mind, largely because the jet engine was developed to a high degree during the War with the help of the gas turbine, which is the engine providing the propulsion. The gas turbine as a commercial article is relatively new, and the research during the War on this new form of engine has helped it along commercially so that it has many uses other than in aircraft.

How does the gas turbine work? We are all familiar with the petrol engine, with the compression of a mixture of petrol vapour and air in a cylinder, with its ignition and expansion to provide useful work. This petrol engine cycle is a discontinuous process, taking place in definite stages. The gas turbine cycle commonly used, called the "constant pressure" cycle, is a continuous process—it goes on all the time. The three essential processes—compression of air, ignition and combustion of fuel, and expansion of the burnt gas and air—instead of taking place in three distinct stages in a cylinder, as in the petrol engine, take place continuously in three distinct parts of the plant, called the compressor, the combustion chamber, and the turbine. The turbine is connected to and drives the compressor (see Fig. 1), and if one imagines the engine in operation, one can follow the process through. Air is drawn into the open end of the compressor at A, and is passed by the series of connected "fans" of the compressor to the other end. As the air passes each stage it becomes compressed, and incidentally it becomes hotter. An aircraft compressor will compress air generally to a quarter of its original space, and in the process raise the temperature from the normal air temperature of 20° C. to about 150° or 200° C. The compressed air now leaves the compressor at B and passes into the combustion chamber where the paraffin or the fuel oil is already burning.

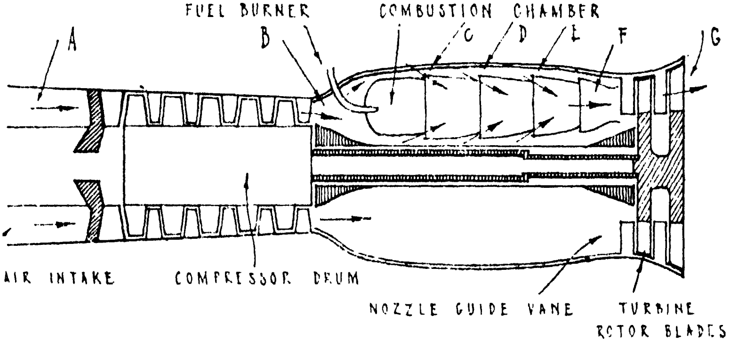


Fig. 1. Gas turbine with axial compressor and two-stage turbine.

The air entering at different points C, D, and E along the combustion chamber wall mixes with the burning gas. We now have a mixture of gas and air under pressure and at a high temperature, and so it is in a suitable condition to perform work. The gas and air mixture now passes to the turbine at F, where it expands, falling in both pressure and temperature, and furnishing the turbine with energy to rotate and drive the compressor and the generator or gearing for a loco, or whatever unit is to be supplied. In the jet-propulsion engine there is generally only one stage of expansion in the turbine; the remaining energy in the gas is used to propel the aircraft as it exhausts through the jet-pipe of the aircraft. This process goes on all the time and, as all the machinery is rotating, there is no backward and forward or "reciprocating" part as in the steam engine or in the petrol engine. This absence of reciprocating action is important, since it means less vibration in the engine, less need for oiling parts, and less wear. In practice the amount of oil needed for lubrication is quite small.

The simpler cycles of the engines of jet aircraft are rather inefficient, because the exhaust gas is very hot and goes to waste. Consequently, they would not serve for industrial use without modification and refinement.

For use in industry, an engine stands or falls on its thermal efficiency of operation; that is, the proportion of useful work to turn machinery or generate electricity, to the total heat put into the engine. The efficiency of a gas turbine is very dependent on the highest temperature at which it will operate. Also the amount of work that can be obtained from a particular size of machine increases, and this is very important to the designer. It is termed the *specific output* and is expressed as horse-power per lb. of air passing through the turbine in one second; as the turbine has a limiting "swallowing" capacity, this is the same as saying h.p. per pound weight of a particular design of machine. Roughly speaking, the hotter the gas passing into the turbine the higher the efficiency, but full use cannot be made of the higher temperatures because the materials, particularly those of combustion chamber and turbine, will not stand them. If too hot, the metals will melt, or even if they are not hot enough to melt, they will oxidize and burn away. This accounts for the large quantities of air supplied by the compressor, far in excess of the quantity required to burn the fuel. As a rough figure at the present time the air excess is about four times. This air is used to bring the inlet temperature to the turbine down to about 700° or 750° C., which can be dealt with adequately by the materials we have now for this type of work. The air is also used to cool the combustion chamber walls.

So far we have described only a simple cycle as in Fig. 2, and that is relatively inefficient. To increase the efficiency various devices are used. The first, as in Fig. 3, is to recover some of the heat of the exhaust from the turbine, and use it to heat up the air coming from the compressor. Then it is obvious that less fuel will have to be burnt to reach the same gas temperature, and fuel will be saved; there is a maximum for each temperature depending on the compression ratio of the engine. For expansion ratios of 5 and above, it is not convenient to do it all in one part of the engine, and two or sometimes three compressors are used. Now in compression the air is heated and then takes up more space than it would if it were cold. Consequently if we cool the air in between each compressor by passing through pipes cooled with

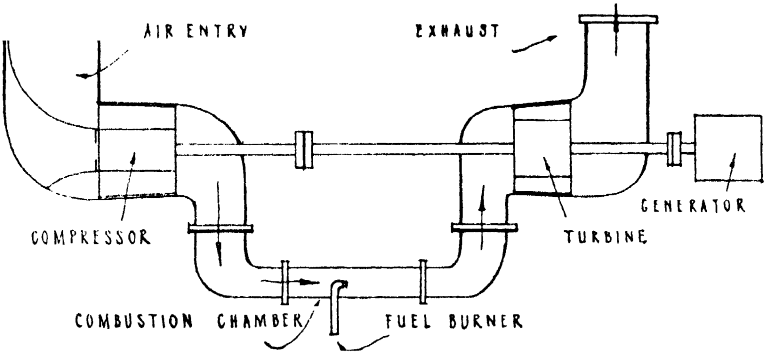


Fig. 2. A simple gas turbine.

water, we can design smaller compressors which will save cost, and, more important, will take less energy to be driven, and so improve the efficiency of the whole engine.

Another important effect of the "heat exchanger", where we recover heat from the exhaust, is that it makes the engine more economical, especially when it is not running full out. This is particularly important for ships and locomotives, where for most of the time the engine is cruising at maybe only half-load, and full load is required only for starting, for climbing gradients, or for emergencies. The curve in Fig. 4 shows this well. Cycles can be made very much more complicated, and whether this is done—which will increase the price of the engine—depends on whether it will be worth it in saving the particular fuel that is to be burnt.

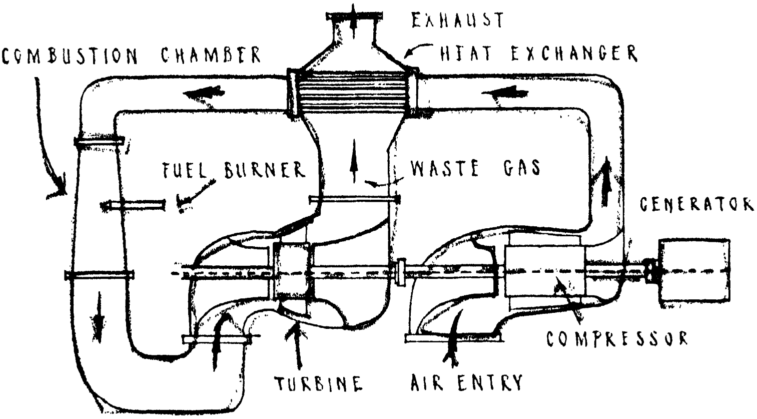


Fig. 3. A simple cycle with heat exchanger.

In addition to being dependent on temperature, the efficiency also depends on pressure. At high altitudes more fuel will have to be burnt for the same power in a stationary gas turbine, and for aircraft it is wise to fit rockets or other means of assisting take-off, because the specific thrust is reduced by the lower pressure of the atmosphere. Operation at low temperatures has a beneficial effect on the efficiency, so that a 5-degree drop in temperature of the air is about equivalent to an increase in turbine temperature of 15 degrees. This makes the gas turbine attractive for use in cold climates.

In general the gas turbine uses one of two types of rotary compressor, the axial or the centrifugal type shown in Fig. 5. In the centrifugal compressor, which can be double-sided as shown, or single-sided only, the air enters at the eye, at A, and is whirled by centrifugal force between the vanes to the outlet at B, becoming compressed by the aerodynamic forces. As the air leaves the outlet at B at high velocity, it is slowed down and the kinetic energy due to this high velocity is converted to pressure energy in the "diffuser" space before reaching the combustion chamber. In the axial type of compressor the air proceeds in stages along an axial direction of the rotating drum which carries the deflecting blades.

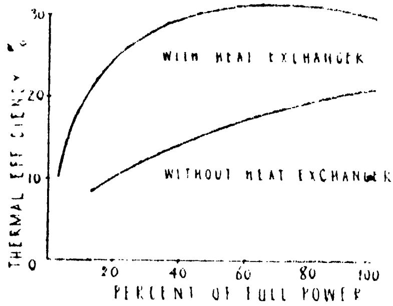


Fig. 4. Efficiency at part load.

There is a considerable difference of opinion among engineers about the merits of the two types. The high-speed Whittle type of jet engine was successfully based on the double-sided centrifugal compressor; later aircraft engines such as the Avon and the Sapphire use axial compressors. For use in aircraft the centrifugal compressor is lighter, but since it is of larger diameter than the axial which would do the same job it presents a greater area of resistance in an aeroplane structure. The efficiency of the centrifugal compressor is lower than that of the axial (rough figures are 75 per cent and 83 per cent respectively), but the former type is more robust, cheaper, does not collect dirt so easily, and is easy to start up. The centrifugal is also limited in that it is difficult to manufacture with a degree of compression (pressure ratio) greater than 4·25 to 1. However,

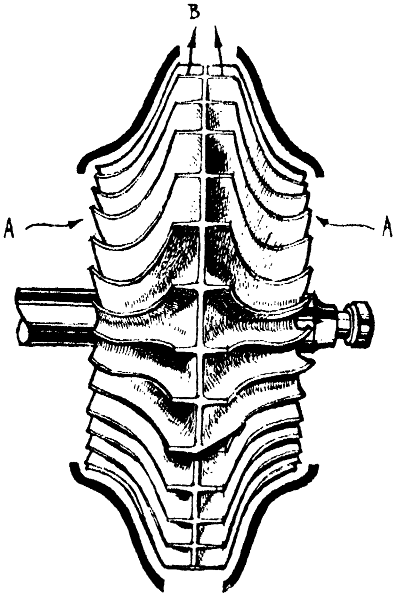


Fig. 5. Centrifugal compressor.

the arguments between the two schools of thought will be settled only by the results of experience with turbines when they are used in a variety of ways.

Jet propulsion is the most popularly known and certainly the most spectacular use of the gas turbine. It was developed during the Second World War as a means of providing an aeroplane of greater speed and rate of climb than any previous type of engine could give. Though it is relatively inefficient, it provides a greater amount of power in a smaller space and with less weight than a piston engine can do, and these things are very important, particularly in a fighter aircraft. After the war, aircraft firms turned their attention to the economics of the jet engine, and of its relation, the turbo-propeller engine—in which the exhaust used as thrust in the jet engine is turned to a turbine driving the propeller. If Fig. 6 is studied, various interesting points of economic advantage can be seen.

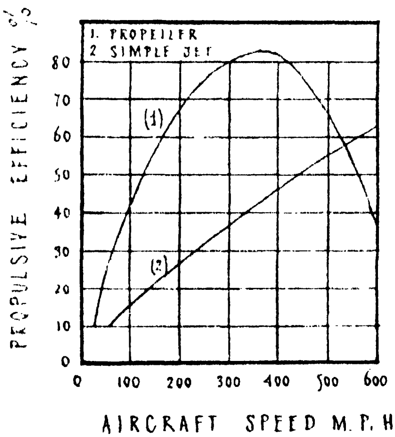


Fig. 6. Efficiencies of jets and propellers in aircraft.

At low speeds and altitudes the propulsion efficiency of the jet is much below that of the propeller. For the best use of a turbo-jet engine for transport, high speeds of 450 m.p.h. and above have to be used, and the aircraft must fly at 35,000 to 40,000 feet. Consequently, only long-range use of 2000 miles or more such as Atlantic or Empire routes appears to have any paying property, because we must take into account the proportion of the whole time the aircraft takes to get to 35,000 feet, and the proportion of the total fuel that doing so will consume. For example, on a trip from London to Paris of 150 miles, a civil type aeroplane would not get to 35,000 feet before it would be required to come down again.

In between the piston engine and the turbo-jet, there is a gap filled by the turbo-propeller engined aeroplane. On the basis of freight-carrying, a useful table has been prepared by Armstrong-Siddeley.

| Condition | | Engine | | | | | |
|---|---|---|---|---|---|---|---|
| | | Piston | Turbo-prop | | Turbo-jet | | |
| Power plant weight, per cent of all-up weight. | | 14·9 | 10·0 | | 7·0 | | 8·0 |
| Height (feet) | | 20,000 | 25,000 | 30,000 | 25,000 | 40,000 | 40,000 |
| With 10% Payload | Range (miles) | 4950 | 4500 | 5050 | 2800 | 4250 | 4200 |
| | Speed (m.p.h.) | 280 | 330 | 315 | 480 | 395 | 475 |
| | Ton-miles/gallon | 4·6 | 3·8 | 4·5 | 2·15 | 3·4 | 3·5 |
| With 20% Payload | Range (miles) | 3550 | 3300 | 3600 | 2150 | 3050 | 3100 |
| | Speed (m.p.h.) | 270 | 320 | 305 | 460 | 385 | 445 |
| | Ton-miles/gallon | 7·8 | 7·1 | 7·7 | 4·15 | 6·15 | 6·5 |

This clearly shows that the turbo-propeller stands out, as it has greater flexibility of operation than either the piston or the jet. To obtain the best results it must cruise at 25,000 feet or better still over 30,000 feet. In comparison at 35,000 feet, a turbo-prop aeroplane can cruise at 420 m.p.h. with a 10 per cent pay-load for 3500 miles, while the piston-engine version could only cruise at 340 m.p.h. or 80 m.p.h. slower.

Except in special circumstances, there is no present application of the gas turbine for large-scale electric power generation. This is mainly due to economic facts. Large steam turbine sets of modern design and consuming low-grade coal have efficiencies of 31 or 32 per cent and diesel engines burning oil of 32 to 35 per cent. At the present time, gas turbines that can be used commercially for continuous power generation have efficiencies no higher than 30 per cent, and have to burn oil of as high a grade as do diesel engines. So obviously it would not be a good business proposition to use gas turbines in this country where coal is easier to get and is much cheaper than oil, even though the cost of manufacture of a gas turbine is less than that of a steam turbine. Having thus put the position at the present time, and in a very black and white manner, it should be explained that the arguments for the use of different types of engine for power generation are complicated and it is interesting to review some of the factors that may affect the future.

First of all there are some advantages fundamental to a gas turbine. While the steam turbine and the diesel are at the peak of their development, and cannot be expected to increase more than 1 or 2 per cent in efficiency, the gas turbine is at an early stage in its history and there is no obvious limit to increase of efficiency and performance. The gas turbine requires very little water, either in a boiler to be converted to steam or in cooling towers, as compared with the steam turbine. So the gas turbine can be put at or near the place where the fuel—coal, for example—is mined, since it is cheaper to transport electricity than coal. Gas turbines would take up much less space and this would lead to less expensive buildings than the modern type of power station we have become used to seeing. Experimental gas turbines have already run on coal, and it is the development of coal burning, by one of several ways, that offers a very great hope for the future. It must not be thought that it is difficult to burn coal. It is not, but there are problems with the open cycle type of turbine in which the burnt gases pass through the turbine, since coal—as does heavy residual oil—contains ash and grit that will damage the blades and other parts of the turbine. At the present time three ways of burning the coal are being tried. First, directly in the open cycle turbine, removing the ash and grit before it enters the turbine. The second way is to convert the coal to gas, which after cleaning can be burnt without any trouble in the turbine, and the third way is to use a closed turbine cycle, in which air is heated by the coal in a boiler—called an "air boiler" (see Fig. 7)—and circulates round the system.

If a gas turbine plant is built without a lot of refinements and it is intended only to use it occasionally as a standby, then it can be made cheaply, and the fact that it is not very efficient in burning fuel will not matter very much because the fuel will only be burnt for a short time—when the plant is needed. In this case it is essential that the initial cost of the plant should be low. With this in mind the Metropolitan Water Board have ordered three standby turbines for their pumping plant at Ashford in Middlesex. In Switzerland too there are some plants which are relatively large, about 20,000 kilowatts, and these are used in the winter to supplement the hydro-electric plant in the country. These are of higher efficiency than a normal standby plant, particularly when they operate in cold weather.

Already a gas turbine has run successfully on trials in a motor gunboat (the MGB 2009) of the British Navy.

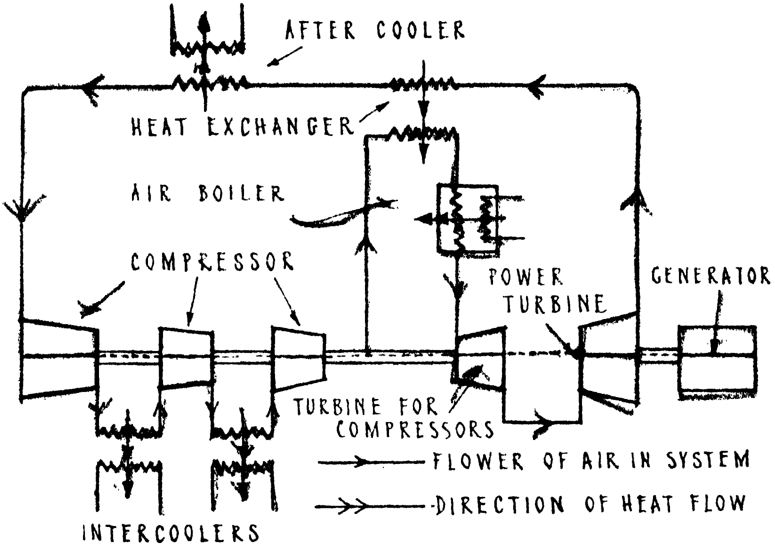


Fig. 7. Closed cycle gas turbine—air is the circulating medium and no products of combustion enter the turbine.

This turbine was converted from an aircraft turbine, of Metropolitan Vickers, by putting in a power turbine to drive the propeller shaft, and was fitted in place of the centre engine of the vessel. Just as was found with the case of aircraft, this type of engine does a job that cannot be done any other way. It is smaller and packs more horse-power into its smaller space. It is also, and very important for a naval vessel, easier to maintain and overhaul than a diesel engine. For somewhat the same reasons a gas turbine is being built to be fitted in a frigate. Conditions are somewhat difficult as, even in war-time, a larger vessel than an MTB or MGB spends most of its life at cruising speed, and seldom requires the whole power of its engines. So either it must be economical with fuel when running the engines at less than half load, or boost engines must be fitted for battle or evading action.

For cargo vessels the size of the fuel bill is all-important. The owner of the vessel must also be able to fill up with fuel at any port of call, and he must be sure his ship will always make port. At the present time, gas turbines cannot yet use any fuel oil, and none have been built to prove their reliability in service on the high seas. This knowledge will come. The Anglo-Saxon Oil Co. have fitted one of their tankers with one gas turbine to replace one of the four diesel engines normally fitted, and with this they will get useful experience.

For fast passenger vessels the situation is different. Speed and comfort are advantages, and both can be assured with a steam or a gas turbine engine, since both are free from the vibrations of the big marine diesel. The gas turbine takes up much less space than either the diesel or the steam turbine. For so-called "cross-Channel" services, of up to about 36 hours, it is uneconomic to use steam turbines since so much time is spent in port compared with the time spent earning money by carrying passengers. The gas turbine, which can be started up quickly, has an advantage here in spite of lower thermal efficiency, and as this type of boat has a fixed schedule of runs, it can always be sure of re-bunkering with the right grade of fuel oil.

Almost everyone who has had anything to do with the

# PLATE XI. ANTS

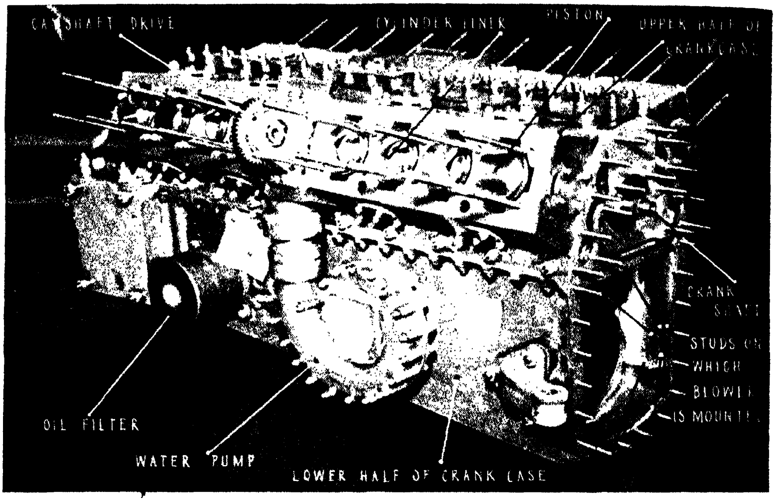
Wood ant about to squirt formic acid (*Picture Post Library*)

Twenty-year-old ant-hill in Surrey (*Picture Post Library*)

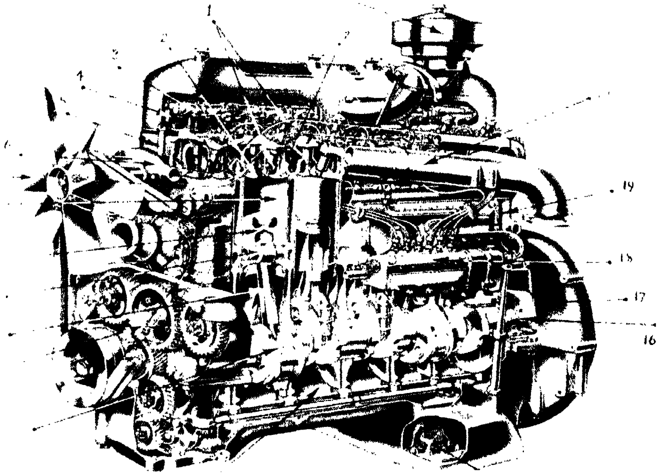
## THE SCIENCE OF SPRINTING

Jesse Owen starting a sprint (*Associated Press*)

# PLATE XII. RACING CAR AND BUS ENGINES



The B.R.M. engine (*By courtesy of B.R.M.*



Engine of a London bus (*By courtesy of A.C.V.*)

1. Injector. 2. Inlet valve. 3. Valve rocker. 4. Push rod. 5. Cylinder head. 6. Water pump. 7. Fan. 8. Cylinder. 9. Piston. 10. Gudgeon pin. 11. Connecting rod. 12. Timing gears. 13. Crankshaft. 14. Sump. 15. Lubricating oil strainer. 16. Crankshaft output flange. 17. Crankcase bell housing. 18. Fuel injection pump. 19. Cylinder block. 20. Exhaust manifold. 21. Air strainer. 22. Exhaust valve.

gas turbine has thought at one time or another that it would be exciting to have a motor-car fitted with one. In this country the Rover Car Company have built a turbine recently and fitted it to a car, and incidentally in a motor-boat as well. As a car or lorry engine the gas turbine has many advantages, but it has one great drawback—it is very expensive in fuel to run it. Consequently, all the advantages, which will be considered here, are outweighed for a long time in the future by this greediness for fuel, and except in some special cases, such as some special military vehicles, the gas turbine car and lorry will not probably be seen commercially on our roads. But it would be interesting and informative to go through the pros and cons of this question, about which many engineers are arguing at the present time.

Up till now all the turbines that have been built have been for higher horse-powers than are usually necessary for road or even for railcar use. It is even doubted by some whether it is possible to build an engine of about 40 h.p. which would suit the medium-size car. This is partly due to the expense of making an engine in a small size accurate enough for the purpose, and partly because it is not known how the gases would behave in flowing through compressors and turbines of this size. For a larger horse-power, about 160, suitable for a bus or lorry, these difficulties are not so great. The smaller a turbine is the greater the speed at which it will run, and so the gearing required will be more special to reduce the number of revolutions of the power turbine to that required for the shaft. The design and manufacture of gears has improved considerably in recent years, and so this is no longer a real problem. The power turbine will have a wide range of working, and this will mean that fewer gear changes are required for a lorry engine and none, except a reverse, for a car engine. This would make the engine cheaper and simplify the driving, since the throttle and brake only are necessary. As you know, a normal piston-engine car can be slowed down by changing into a lower gear ratio, the engine acting as a brake. This cannot readily be done with a turbine engine, and various ways are suggested to overcome this snag which drivers would notice. Some engineers claim that it will be simple to lay out a car design with a turbine, and that with a lorry both space and weight will be saved. Weight can be important as it means a greater paying load can be carried in a vehicle. Other advantages, while they are not outstanding, are important—the fact that no cooling is needed, and that the lubricating oil required is only a small fraction of that for the piston engine, for example.

But the great drawback, as we have seen, is fuel cost. The Rover car, with an output of 100 b.h.p., consumes 1·6 lb. of fuel per b.h.p. per hour. This corresponds to about 6 or 7 miles per gallon. A diesel lorry engine of about the same power consumes 0·4 lb. of fuel per b.h.p. per hour. A heat exchanger fitted to the car engine would reduce the 1·6 lb. to about 0·8 lb. of fuel per b.h.p. per hour, but it would increase the cost and size of the engine. It is hoped to be able to design a heat exchanger of small size, and this would improve matters, particularly when the engine is running at cruising speed.

The first really successful gas turbine to operate, apart from a standby plant in an underground shelter in Neuchatel in Switzerland, was the Brown-Boveri locomotive. Since the war this loco has run regularly on the French National Railways. A somewhat similar design has recently been built and has run for the past year on the Western Region of British Railways. Another of British design and manufacture has run recently in the same region.

All these three locos use fuel oil, and also transmit the power from the turbine shaft to the loco driving-wheels by electric generation. In other words, electricity is made first and used to operate an electric motor to drive the train. This process is a wasteful one, because it destroys one very great asset of the gas turbine, particularly for starting a heavy train in motion—the starting torque or driving twist of the shaft to the wheels. This asset is greater for a gas turbine than for any piston type of engine. The fitting of an electric generator and motor makes the whole much more bulky and expensive than it would be if gearing reduction were used.

For countries where fuel oil is cheap and water scarce, the oil-fired gas turbine locomotive is ideal. It does not need to carry water for cooling, it has less weight than a diesel, and it takes up less space. For example, a diesel of 3,500 h.p. requires two coupled locomotives to accommodate the engine, but a gas turbine of the same power can be placed in one of them. Again less weight means more pay-load.

In some countries—and there are not many where fuel oil is cheap—it would be a great advantage to have a coal-burning locomotive. For example, in travelling across India from west to east, the locomotive passes from a region where oil is cheap and coal is dear and scarce, to a region in the east where the opposite is the case. In most European countries, in South Africa, and in Australia, coal is plentiful in comparison with oil and is at present being used very inefficiently in steam locomotives. Even a modest efficiency of about 16 or 18 per cent would mean a saving of 50 per cent of the coal at present being used for steam locomotives, and about 14 million tons of coal is used annually by British Railways alone. As with all these problems of new types of plant, it is not always as simple as it appears at first, and many aspects have to be considered. The train has to be heated; new engines mean re-training drivers and firemen, and also the crews of men who service the engines. Also not all locos can travel on all lines of the same railway.

While all the applications we have considered up to the present have been to some extent of everyday interest, there is a wide field of application, which, though it is not spectacular, may become the most profitable. This is the general field of chemical industry. In chemical manufacture and in the melting and refining of certain alloys, reactions often take place which involve high temperatures and pressures and as a by-product of these reactions some heat is produced. Sometimes gas which can be burnt is given off. In some cases these processes are combined with waste heat boilers, and the heat is used to generate steam which is often wanted in another part of the factory.

But then it is often possible to do things a better way. Instead of contriving to avoid the waste of heat, it can be used to generate power to drive the process. Thus instead of burning coal or electricity to keep the chemical reaction going, the heat thrown out and going to waste is used to drive a gas turbine, and the whole process can become wholly or partly self-supporting.

One classic application of this type has been used in the U.S.A. for some years. In the "Houdry" process for oil cracking, a "catalyst" is used. This is a platinum gauze which assists the reaction—which would not take place, or only slowly, without it—but which is not itself changed during the cracking process. This catalyst becomes covered in carbon black with time. Consequently, two chambers are used, and as one becomes clogged, the other is switched into use. The clogged chamber is then fired. In effect, it becomes the combustion chamber of a gas turbine, which drives some of the compressors needed to supply the large quantities of air required under pressure for the cracking reaction.

An example of waste heat recovery will shortly be installed at a gas works near Coventry. Here the waste heat from a coke oven is to be used to drive a gas turbine and will generate about 700 kilowatts of electricity. The gases come from the vertical retorts at a useful temperature of about 800° C., and it is expected that the electricity generated will meet all the power requirements of the gas plant.

Another, almost spectacular, example is in the manufacture of acids, such as nitric acid. When ammonia is burnt in air to produce oxides of nitrogen, a large amount of heat is produced and, depending on the process used, this heat is very suitable for the gas turbine. The gases given off are generally at about 900° C. or above and at pressures of 3 to 6 atmospheres. In theory the whole of the power needed to run the process could be regenerated, and used to blow all the air required to mix with the ammonia in the oxidation process. The saving is quite large because with a plant producing 40 tons of acid a day, about 800 kilowatts are needed. Taking everything into account, a real saving of about £30 a day would be gained.

The whole of the future of the gas turbine lies in successful and patient application to jobs of work which cannot be done as well by other means. Particularly in the future it will be necessary to burn fuels which are at present wasted. Already in various oil fields, gas turbines are installed to burn natural gas, and drive the pumps for the oil wells. Plans have been laid to dry and burn peat on or near the peat bog in gas turbines, and so save the cost of transport. The gas turbine, having worked out one area, would then be moved to a new site.

The successful burning of coal in gas turbines in this country would mean that many thousands of tons of low-grade coal could be used to generate electricity. The lower efficiency of the plant in comparison with the modern steam plant would be of little consequence if this coal were turned to good account.

## THE PROBLEM OF THE FOOTBALL FAN

Jones was equally keen on both rugger and soccer. Every Saturday afternoon during the season he watched either the rugger match at Tackleham or the soccer match at Kickham. He did not mind which ground he went to, but he hoped to see about half the games at each. Electric trains both to Tackleham and to Kickham left his local station from the same platform, and each left at ten-minute intervals. When Jones had lunched he just walked to the station and took the first train that came in, without worrying about the exact time. Sometimes he went to Tackleham, sometimes to Kickham, but at the end of the season he found he had been to Tackleham 27 times and to Kickham only 3 times. Why?

(Answer on p. 244.)

# Ants

### A. C. FITT

EVERYBODY is familiar with the appearance of an ant heap. Indeed you may be only too familiar if you are unlucky enough to have had one in your lawn or the inhabitants of one in your pantry. But have you ever paused to consider what wonderful animals these are and how and why they differ in their habits from almost any other insects? Although it is obvious that they do differ from most insects the reason will perhaps not strike you at once. It is that they all live together as a community; that is, they are social insects. About the only other animal that lives in such highly organized communities as the ant is man. In fact in many ways ants are far more efficient social animals than we are because they are more specialized for social life. This, as we shall see, is both an advantage and a drawback.

In order that we may fully understand the social structure of an ant colony let us consider the organization that ants have built up. One of the great questions which we have to decide as we grow older is what we are going to do when we leave school. That is how we are going to earn our living. There is an almost endless list of trades and professions from which to choose. Moreover it is a choice; indeed, some people try a number of jobs of different types before settling down to their life's work. This is what separates human society from that of the ant, for the ant has no choice. It is destined to a certain job the moment the egg from which it will hatch is laid. In order to understand this we must have some knowledge of the life history of the ant and the organization of the nest. Let us then take a peep inside an ant heap and see what is happening.

When we open the nest there will be great scurryings to and fro of many ants—some carrying little white cylindrical objects; but if we know what we are looking for we shall soon find one individual somewhere in the centre of the nest rather larger than the rest. This is the queen. She is the only true female in the nest and her sole duty is to lay eggs. By far the majority of the remaining ants will be workers whose duty, as their name implies, is to do the "housework". That is to say, they collect the food, and keep the nest clean; they look after the eggs and the grubs when the eggs hatch; they feed the grubs and guard the cocoons when the grubs become pupae. The pupae are the white cylinders we noticed the ants carrying when the nest was first opened. The workers, when danger threatens, try to save the cocoons. Also present in the nest in the summer months are some winged males, the drones. These do no work and their sole duty is to fertilize the queen. That is, to pass over to the queen sperm to fertilize the eggs that the queen will lay in due course. So here we have a community with three different types of individual, and in some communities many more specialized types, each with its own job and incapable of doing any other. It is by a most remarkable device of nature that these specialized types are brought about.

If you keep your eyes open on a fine summer's evening in July or August, you will sooner or later seen an ant swarm. This will consist of a vast number of virgin queen and male ants. These will not be from one nest only but from many nests in the neighbourhood, for nature arranges a mass swarm, by what means is not known. During this swarming mating takes place and the males transfer sperm to the female. The importance of a number of nests swarming at once is that it increases the chances of any particular queen being fertilized by a male from another rather than from her own nest. This leads to a more healthy stock. When the queen has been fertilized the males usually die and are not replaced in the community until the following summer. The stock of sperm the queen receives from the drone lasts her the rest of her life.

The queen, however, comes quickly to earth, casts off her wings (often biting them off), digs a cavity in the ground, and buries herself. In this cavity she lays eggs and tends them until they finally hatch through the larval (or maggot) stage, then the chrysalis (or pupa) stage, to the adult. This may take a period of several months. During all this time the queen has nothing to eat, and into the bargain she has to feed the grubs on her own saliva. As a result of this she is rather weak when the new colony finally comes into being. However, all is now well, because all the freshly hatched ants are workers and dance attendance on the queen. She at once begins to lay eggs. This she does through the rest of her life, which may be several years as ants are long-lived creatures. The queen has it in her power to dictate the sex of her offspring. As you see, she is only fertilized once during her life and must store the sperm. This she does in a special sac inside her body. Every egg, however, is not fertilized by a sperm; those of the male are not. So if the queen fertilizes an egg it becomes a new queen or a worker. If she does not do so, it becomes a male.

The difference between the queen and the workers is caused by different diets. The grub of a worker is fed on a much poorer diet than that of a future queen. So the poor workers may be regarded as those who have been robbed of their birthright by malnutrition.

Having now an idea of the life history of the ants in general, let us have a look at the ants' home, the nest. Although this is usually under the ground its position varies widely, and some primitive ants do not build nests at all. The ants which make no nests, for example the legionary ant of South America, live in "camps", from which they sally forth, usually at night, on foraging expeditions in vast numbers in columns several hundred yards long. These ants are meat-eaters and stories are told of the devastation that large numbers of them can do. They will clear quite a large area of all the small animals and will even attack such animals as goats and pigs that are tethered. This type of ant is probably fairly primitive, as it has developed its social life but not its homemaking instincts. Just as man's most primitive instinct is to hunt, kill, and eat animals, so probably it is the ants'. However, this method of existence is fairly chancy and, as is all too clearly shown by the present size of our meat ration, food from animal sources is much more difficult to obtain than that from plants. So most of the more advanced ants have become vegetarians or "mixed" feeders.

The reader will, I expect, know well the type of places in which nests of ants can be found. The ordinary garden ant makes a burrow in the ground, often under the lawn or under the hard surface of a path. In this latter case you can often see the tracks made by the workers passing and repassing on their foraging expeditions. Another common place for ants to nest is under paving stones, and you may see workers scuttling down the entrances of the nests in the cracks between each stone as you walk down the street.

Some ants, particularly those that get into pantries and places in the house, have the annoying habit of nesting in the foundations, from whence it is exceedingly difficult to shift them, or even in garden walls where they will loosen the mortar.

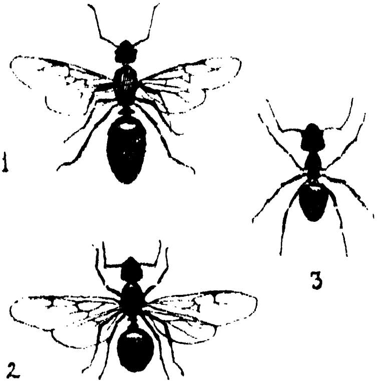


Fig. 1. The Great Wood Ant; (1) male; (2) female; (3) worker.

Of course, not all ants live completely underground or even in the ground at all. Wood ants, for example, construct burrows in the ground, but above these, for additional space, they construct a mound composed of pine needles, small twigs, wisps of hay, and so on. This mound may be several feet in height and although on first sight it appears to be rather haphazard in construction this is not so. The entrances are clearly defined and are closed when not in use by a sort of "janitor" ant who puts a twig in position. The wood ant incidentally is a very conservative creature and if left undisturbed will occupy the same nest, generation after generation, for many years.

Another ant which does not live under the ground, and indeed has little connection with it, is the red tree ant of India and Malaya. This is sometimes called the spinning ant because it makes its nest by sewing leaves together with silk threads! This amazing feat is done like this. The ants themselves cannot make silk but, of course, their grubs do so when they pupate and go into a cocoon. One ant steals some of this silken thread from the grub as it is spinning it and takes it to the nesting site. Here another ant punches holes in the leaves and then holds the two edges together while the first ant sews them up! These nests cannot, obviously, attain the size of those of the ground-living ants, but go up to nine inches or more in height. Incidentally it is a brave man who climbs a tree with one of the nests in it. The ants object to the intrusion on their privacy, and bite in no uncertain way!

To return to the food of ants. We have seen that the more primitive ants are meat-eaters while the more advanced types are plant-feeders or exist on a mixed diet. This is not entirely true, for the wood ant feeds very largely, at any rate in the summer, on insects; if you keep your eyes open you will see the workers of this species dragging home their food. This is an amazing sight to watch. You will see twenty or thirty ants all pushing and pulling the body of perhaps a beetle fifty times their size along the track. All the work seems to be co-ordinated and everybody knows where to go and what to do. How this is directed is a mystery. There appears to be no foreman shouting instructions! By eating insects these ants are a benefit, because they rid the trees of many pests.

The garden ant, which is common all over Britain, enjoys a varied diet of insects and other animal food, together with seeds of plants. Like many ants they are farmers. They feed on honey-dew, a sugary substance exuded by green-fly, which as you probably know is a common garden pest. These green-fly attach themselves to plants and feed by sucking out the sugary sap of the plant. As a rule they eat much more than they require and the surplus comes out as honey-dew. The garden ant has at least two methods of looking after these insects which it tends as man does his cattle. Sometimes they build banks of earth round the plant on which the green-fly are living; sometimes they take the green-fly into the nest and feed them on the roots of plants which are jutting through the walls of the burrows. These green-fly are milked by the ants, who stroke them

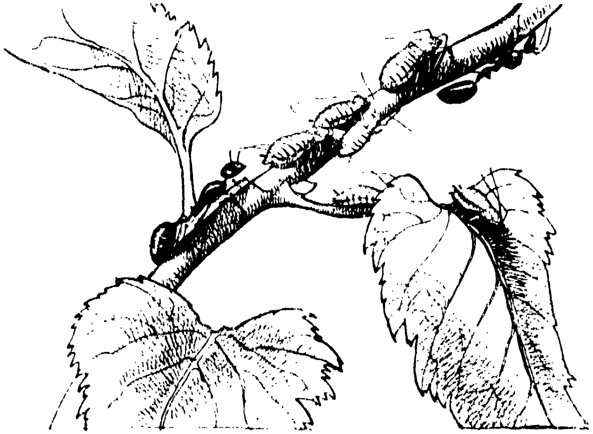


Fig. 2. Ants visiting a colony of Aphis to milk them of honey-dew.

and cause them to exude more honey-dew. The green-fly, of course, die off during the winter, but before doing so they lay very resistant eggs which will hatch the next spring into more green-fly. The ants have been known to collect these eggs and store them over the winter; when the eggs have hatched out the ants have placed them on a plant or on plant roots and tended them! Just as human farmers harvest the grain in autumn, so do ants; seeds are collected by the workers and stored in the nest. Before being put in the granary the seed has the germ removed by the ant to prevent it germinating. From time to time the ants even bring the store seed by seed to the surface to air it.

The harvester ants of America go even further than this; they actually plant their "ant rice" in specially cleared patches of ground near their nests. The fungus-growing ants collect leaves which they drag into their nest, and they cultivate and eat the fungus which subsequently grows on the decaying leaves. On moving their nest these ants will carry some of this fungus to the new nest and plant it again in special beds prepared for it.

The last word in food storage is perhaps that of the honey-pot ants who live in South America. These ants have a special type of worker called a "replete". The other workers go out from the nest and collect honey-dew; this they regurgitate and feed to the "repletes", who swell until they have become enormous. When at last these repletes are full of honey they are hung from the roof of the nest, where they form the reserve food of the nest—literally just honey-pots! Theirs must be a very dull life, as they remain hung from the roof for months at a time.

You can see that in many ways the civilization of ants is as highly organized as that of human beings, particularly in the nest. Some types of ants have special soldier ants whose task it is to defend the nest. The robber ants follow even more closely the habits of man. These ants raid the nests of other ants and carry off the pupae to their own nests, where they hatch out. They are then used as slaves by their captors and do the work of the nest. The attack on another nest is a highly organized affair, exactly like a human battle. Advance guards find weak places in the defence, and where the resistance is strong, reinforcements are sent to make a flank attack.

As you can see, ants are very successful animals. They are found in almost all countries, and almost from pole to pole. Why is it, then, that they do not dominate the world as man does—or rather, likes to think he does? The reason perhaps lies in their great specialization. An ant is capable of doing only the job to which it is born, and this job it will do magnificently. It cannot, however, change its job, and so it is not capable of adapting itself to changing circumstances. A man is a far less specialized animal: if one job is completed, or if he does not like it, he can change to another. In other words, man can move with the times whereas ants cannot.

If you have been interested by this account of the life of ants, you may like to have some practical suggestions for keeping ants in captivity so that you can see them at work and study their habits. It must be emphasized that these creatures should never be kept in the house, as it is very difficult to make the box absolutely ant-tight! Ants in the house can be a very great nuisance.

The container for the "formicarium" or ant-house can be made from a wooden box, a sheet of glass, some strips of wood or beading, and some putty. The simplest kind of box to adapt is a seed-box with a depth of two or three inches—and we will assume that you have one available. It is important not to use a box which is deeper than this, because if you do, the ants will keep away from the glass front and you will not be able to observe them at work.

Details of the construction of the formicarium are shown in Fig. 3. Carefully remove one of the longer sides of the seed-box and keep it for the lid. The bottom of the box is to become the back of the formicarium, and the open top of the box is to become the glazed front. If we assume that the sheet of glass is of the correct size, the next job is to prepare the box to receive the glass. The simplest method is to nail strips of beading round the inside edges of the three sides. The beading will prevent the glass from falling out, and when the box is filled with soil, the glass will be pressed

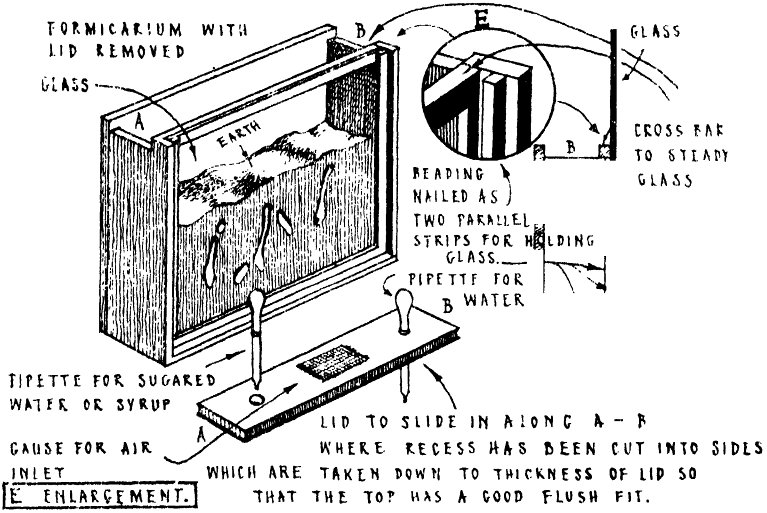

FORMICARIUM WITH LID REMOVED
GLASS
A
EARTH
B
E
GLASS
CROSS BAR TO STEADY GLASS
B
BEADING NAILED AS TWO PARALLEL STRIPS FOR HOLDING GLASS.
PIPETTE FOR WATER
B
PIPETTE FOR SUGARED WATER OR SYRUP
GAUSE FOR AIR INLET
A
LID TO SLIDE IN ALONG A – B WHERE RECESS HAS BEEN CUT INTO SIDES WHICH ARE TAKEN DOWN TO THICKNESS OF LID SO THAT THE TOP HAS A GOOD FLUSH FIT.
E ENLARGEMENT.

Fig. 3. Construction of a formicarium.

tight against the beading. To make the glass more secure a supporting strip of wood across the top of the box, and underneath the glass, would be an advantage.

The next problem is to fit an ant-tight lid to the box. The spare side of the seed-box can provide the material for this. Cut it to the shape shown in Fig. 3, and cut notches in the tops of the sides of the formicarium to receive it. When you have made sure that the lid is a good fit, cut two holes in it to take two fountain-pen fillers or similar dropping tubes. One of the tubes is used to feed the ants with syrup and the other to provide drinking water. The ants will also need some ventilation; a small piece of fine gauze tacked over a third hole in the lid is the simplest way of achieving this.

The formicarium is now structurally complete, but before you put ants in it you must make sure that it will be ant-tight. Use putty to fill any gaps, cracks, or holes that you can find.

Now we have to catch some ants. First find a nest in a place where you can easily dig. Lay the formicarium on its back with the glass front out. As you dig up the nest transfer it to the formicarium, spread it out, and look for a queen. When you are sure you have a queen and a fair number of attendant ants, with the formicarium about three-quarters full, replace the glass, stand the formicarium the right way up, and put the lid on firmly. Brush off any ants that are on the outside, and make sure that the occupants are not escaping through any gap you have overlooked. Carry the formicarium to a shed, give your ants a few drops of syrup or honey, and leave them undisturbed to organize their new home. Give them food and water every day and vary the sugary diet by giving them a dead insect occasionally.

# War in Space

### JOHN PRESTER

THE rocket had now reached a height where they could see the curvature of the Earth. All the familiar markings of the continents were dimly seen through the stratospheric mist, and gradually the Earth became more like a globe in a classroom. But here in the deep of the interplanetary space it was nothing like a classroom. The inside of the rocket ship was small, but the crew had comfortable seats. As they looked out of the windows of the rocket ship, the thing they were most conscious of was the blaze of light from the Sun. They were now two hundred miles above the Earth. The navigator, John Cabot, turned to the captain and pilot, Tony Martin.

"Time to switch on the booster, Tony. We're two hundred miles up."

"Thanks, John. Donald, come and have a look and see how I do this."

Donald Roper was the atomic gunner of the rocket ship. Normally he would have little to do with his guns, and Tony was teaching him how to pilot the rocket. Then in case of emergency he could take over the rocket ship and pilot it back. He came back from his position in the nose. The atomic gun was mounted in the front of the rocket, and its aim was made by first guiding the rocket, and then moving the extra few degrees by a hydraulic control. The pilot sat behind him, with the navigator at his side. They had a large transparent dome above them, through which they could see in all directions, and which was fitted with sun screens as a protection from the blinding light of the Sun. The dome was raised up like the cockpit cover in an old-time aeroplane and was made of a special material, Crypto-glas, to stand the very high pressures experienced when the rocket ship passed at speed through the Earth's atmosphere.

Donald came back and stood behind Tony.

"There are only two operations in the boosting," said Tony, "and only two controls. The first is the heating switch here." He touched a white switch in the control panel with his finger. "You put that on first, and the heating element in the booster is switched on. You give it two minutes to get to the proper temperature, and then push this plunger home."

The plunger had a spade grip to it, and moved down into a long bronze cylinder. Tony turned the heating switch on, and they waited.

"Right, two minutes are up," said Tony.

He took hold of the spade grip, turned it round half a turn, and plunged it home. The roar of the booster could just be heard through the walls of the rocket ship, and they began to feel the continuous acceleration that the booster rocket gave. Here in space it was not possible to appreciate the speed at which the rocket moved; only the changes of speed were noticeable.

"It's difficult to say exactly what speed we're doing now," said Tony. "But they reckon that with this booster going we're getting up towards 20,000 miles an hour."

"How do you control it when you're out beyond the atmosphere?" said Donald.

"We have to use our directional anti-gravity screens," said Tony. "The whole ship is lined with a curious substance that is anti-gravitational. That is, the presence of another body near it doesn't attract the metal to it. So all round the body of the ship there are the anti-gravitational screens, and by opening the screens you want you can move the ship in one direction or another. This material was discovered back in the last century by a scientist called Wells. He nearly destroyed the Earth with it before he realized what he'd got hold of. It's a most interesting account to read, and exciting as well as scientific. However, they didn't develop it immediately, but kept the details of the manufacturing process for about fifty years, till they thought it was worth trying it again. Then they decided to use it for the rocket ship force, and it's certainly made these things controllable. But besides the anti-gravity screen, we've got a 'gravity-board' on the rocket floor, so that we always seem to be the right way up. As soon as we get into a planet's atmosphere, or back to the Earth, we synchronize the gyro-stabilizer in and then we are the right way up for that planet, and remain so until we're out in space again. Then we can switch the gyro-stabilizer out."

"What happened before they had this material," asked Donald, "and what do they call it?"

"It's called Gravinul, and before they had it they used to have a lot of fun with missing rockets. They'd shoot the rockets off, and the pilot wouldn't be able to get back. There are several of them still out, cruising round. A few have crashed on to other planets, and some are circling round on a free orbit. The crews of those that are circling round are quite certain to be dead by now, but we don't know about the ones that have crashed. They've crashed on most of the different planets, and they all had radio-senders. But I expect the distances are too great for the little sets, and we haven't heard anything of any of them. They told us that we might be able to pick up some news of them, and they've given us a pretty powerful radio receiver. That's what's keeping John so busy."

They glanced over at John Cabot. Besides navigating, he was operating the radio set, keeping in touch with the Earth-base as well as picking up any stray messages that might come in. The old rockets had all sets working on the same frequency, so there was no chance of missing any messages from them should they still be alive to send any.

Tony, John, and Donald formed the crew of rocket XZ 81, a reconnaissance and fighting rocket of a new type. It had recently been developed by the Interplanetary Research Organization, and had the new features that Tony described to Donald. But the atomic gunner was peculiar to the XZ 81. They had at first thought it necessary only to have a crew of two for reconnaissance purposes, but strong pressure from the Defence Ministry of the Government, helped by a large grant of money, persuaded the interplanetary organization to include a gun. The atomic gun had not been very thoroughly tested until then, because of its immense power. They were uncertain what the gun might do if it were fired off when loaded to full charge, and Donald had been detailed to go with the rocket expedition and report on the performance of the gun if he had the chance to fire it. Although he was an expert on the atomic gun, he had not had much chance to learn anything about the working of the rocket ship before they took off. So Tony was giving him as much information as he could while they were on the trip.

They had been sent out with the order to report on the performance of the rocket ship, and of the atomic gun should they have a chance to use it. They were also told to do as much planetary reconnaissance and observation as they could, and to try to contact some of the missing rockets if they heard or saw anything of them. Tony had privately said that it was hard enough to look for a needle in a haystack, but when the haystack was about a million times larger than normal and the needle a million times smaller, they might just as well save their time and energy. But the only trouble it had caused them was to learn how to work the special ultra-short-wave radio, and John Cabot was a radio enthusiast anyway. And they had a specially powerful set, which was always an advantage.

They had now passed well beyond the influence of the Earth, and their gravity meters began to indicate the pull of the Sun. Since the Sun was by far the largest celestial body close to them they had to guard against being drawn too close to it. In order to test the antigravitational controls they decided to go near to Venus first. This was largely because Venus and the Earth were both on the same side of the Sun when the XZ 81 left the Earth, and were nearly as close to each other as they could ever be. The conditions there were known to be suitable for living beings, but Mercury, the nearest planet to the Sun, was altogether too hot. The rocket sped through space, and the Sun loomed larger as they approached the orbit of Venus. They took it in turns to sleep, and John gave Donald and Tony instructions on how to work the radio, so that they were always in touch with the Earth-base.

As they approached the planet, they could see some of its more prominent characteristics, and could see the thick atmosphere which had made it such a mystery to the astronomers of all ages up to the twentieth century. By now several people had made journeys to Venus, circling round the planet without landing. Not all of these adventurers had come back, but much information was now available about the structure and life of the planet. It was definitely established that the life on the planet was of a high order of civilization. It was possible to see engineering works which showed great skill, but as yet no one had got any idea of what sort of being had been able to produce these engineering works.

The crew of XZ 81 had been given orders not to attempt to land on any planet, but to make only a further geographical reconnaissance. On the tenth day out they were within fifty thousand miles of the planet, and to stop their motion in the direction of the planet, they closed the anti-gravitational windows in the forward direction. As they opened the windows at the opposite end, they could feel the attraction of the planets behind them gradually slowing them down.

They were now only a thousand miles from the surface of the planet, which loomed up gigantic ahead of them. John Cabot called up the Earth-base and gave their position. Suddenly he gave a start, and bent down as if to get closer to the radio. Donald looked over to Tony.

"Looks as though he's heard something," said Donald.

They both turned and watched while he adjusted the controls to get the maximum reception. After a short while he took his headphones off and turned to Tony.

"I think I'm on to something. Can we get down closer, and then move about to find the place where this set is?"

"We'll get down closer," said Tony, "and with our stub wings and rudder we should be able to manœuvre in Venus's atmosphere all right. And see if you can pin-point the sender on the radar screen."

John returned to his set and put on the phones again, while Tony prepared to bring the rocket down closer to the planet's surface. They moved down some six hundred miles. John turned to Tony once more.

"I haven't heard them again, but I think that their set must be pretty weak. Can you remember what sort of sets they put in the first rockets we sent out?"

"I can't remember, John, but they ought to have been quite good, because they were supposed to be able to keep in contact with Earth-base all the time. But if they have crashed on to the planet they may have damaged the set. In fact, I'd be surprised if they hadn't. These rockets aren't easy to land gently anywhere except the Earth-base, where we have got the special landing gear that you have seen."

John was holding the headphones in his hand as he listened to Tony. Suddenly across the crackle of the set came a voice, faint, but still distinctly recognizable.

"Hello Earthship, hello Earthship; report signals, report signals, report signals. Over." The voice sounded weary, and at the same time excited, as though the sender had been trying for a long time to do something he was very keen to do.

John clamped on his headphones again.

"Hello unknown station, receiving you O.K. Report my signals. Over."

"Hello Earthship, receiving you O.K. Call this station Mortvain. Over."

"Mortvain!" gasped John. He turned to Tony.

"Remember old Professor Mortvain, from the Rocket Research Laboratories of the University of Paris? Looks as though we have got him at the other end."

He turned back to the set. Tony remembered the name well. Old Professor Mortvain was a French scientist who had been the head of the Rocket Department at Paris, and had been one of the first to go up in an old-time rocket. He had reported on his progress for several weeks, and had circled around Mars as he had originally planned to do. But on the way back he had reported that he was in difficulties, and since then nothing had been heard of him. John was talking to the Professor again.

"Hello Mortvain. What news of your party, and what signs of life around you? Over."

"Hello Earthship. Only Duplessis and I are left. Living with natives, who are approximately human. Very high standard of life and intelligence, but have to report great danger to Earth from them. Over."

"Hello Mortvain, what is this great danger, and how will it occur? Over."

"Hello Earthship. Story is very long and must tell you quickly. General outline now, more later when I can get on to set. Over."

Professor Mortvain did as he said, and told John his story over the next few nights, the only time he could get on to the set. On the way back from Mars they had been attracted off their course by a large comet which had passed very close to them. The deviation had been such that they found themselves headed towards Venus, and could do nothing to turn away from their course. The landing on Venus had only been possible by luck, and Mortvain did not speak very highly of the landing gear that had been fitted to the old-time rockets. He said that they had managed to land, however, and that they were all alive at that time. They had met the inhabitants, who had not molested them, but who had been greatly interested to find them there. He said that although their speech was completely different from ours, and indeed, very difficult for human beings to make at all, they had some highly developed telepathic powers. It was possible for Mortvain to understand them by purely telepathic exchanges, and he had found that in this respect Earth humans had a greater skill than the natives. He could now understand their thoughts without their trying to project their thoughts to him, whereas he could keep his thoughts completely hidden from the natives. It was because of this that he had been able to discover the danger to which the Earth was exposed.

The scientists of Venus were a group of extremely clever men, and had for some time been interested in interplanetary travel. They had not tried to travel to the Earth many times, but kept their trips to visiting the asteroids, Mars and Jupiter. The Earth was a planet of great interest to them, but they had very recently got the idea that the inhabitants of the Earth were hostile to them. This had arisen because of several radio messages they had picked up from the Earth-base. There had been many references by the Earth-base to the idea of colonizing or conquering one of the other planets. The ceaseless activity of the Earth-base's rockets had done little to remove the bad impression they already had, and they had recently evolved a plan to eliminate the Earth altogether. This was going to call for some brave and suicidal rocket crews, but they had been coming forward in thousands when the dangers from the Earth had been explained to them.

Briefly, the idea was this. In the course of the next year, a large comet was going to appear in the neighbourhood of the Sun, and would pass through the orbits of some of the planets. The scientists of Venus had estimated that it would pass close enough to the Earth to be deflected to the Earth if necessary. They were sending out their rocket crews with instructions to knock the comet off its course, and deflect it near enough to the Earth to make the two attract each other. This was going to be done by exploding very high-powered rocket bombs in a great mass to one side of the comet. It was a very difficult business to judge it right, but they had plenty of rockets and bombs, and could afford to lose a great many in the process. And even if the comet did not actually hit the Earth it would still come so close to it that it would do an appalling amount of damage. The progress of civilization would be put back by several thousand years, and the inhabitants of Venus would be able to develop without fear of any interference from the Earth.

Professor Mortvain told all this story concisely and very carefully. He told them many more things about the life and types of animals to be seen on Venus, and the three members of the crew of XZ 81 made as many notes as they could of his conversations. When they asked him how he personally was surviving, he said that he and Duplessis were quite accustomed to their life now, and spoke highly of Duplessis' courage and cheerfulness. The third member of their original crew, Baudot, had been killed in an accident when they first reached the planet, but Mortvain could see no reason why he and Duplessis should not reach a ripe old age and die naturally. Unless, as he said, some sort of a war should result from the ideas of the scientists of Venus.

"But do you think that's likely?" asked Tony.

"It's possible, but it would be waged very strangely," said Mortvain. "It would be mainly like this business they are trying to do now, deflecting comets from their proper path into one or other of the planets."

"Can you do anything there to stop their plans?"

"I've tried, but they won't listen to what I've got to say. But the funny thing is, Duplessis and I are very well treated by them all. They've got a planetary organization like we had on the Earth when I left. That is, there aren't any divisions into countries, but everyone comes under the same control. The head of this organization is a fine person, but we can't make him change his mind. I can see his point of view, too, but I don't agree with it at all."

"What does he say, then?" asked Tony.

"He says that they've got to protect themselves, and he can't bring himself to contact our interplanetary chiefs if they're such bloodthirsty people as they seem to be."

"What do you suggest we can do about it?" asked Tony.

"The only thing will be to get back to the Earth and to contact your chiefs and the United Nations. If I were you I'd go to the United Nations first, because they will be able to control the Interplanetary Research chiefs. Once they know what the danger is they'll almost certainly get out a plan to avert it. But you must make them realize where their danger is, and when it's coming."

They talked further with Professor Mortvain, and decided to go back and report to the Earth-base as soon as they could. They asked him if they should try to land and take him off.

"No," he replied. "It'll be better to have someone here all the time. We can keep in some sort of touch this way. What I would like is to have a better wireless so that I can keep in touch with you all the time. Either bring me one next time you come or give me the one you've got now."

"We can't very well give you ours," replied John, "because we haven't got a parachute for it, and if we just chuck it overboard we shall break it up completely. I'm afraid you will have to wait until the next time we come, or until we get someone else to come up here."

They left the Professor, wishing him all the best of luck, and set out on the ten-day journey back to the Earth. They had been keeping the Earth-base informed of what they had heard from Professor Mortvain, and had told them that they had a message of the greatest importance for the United Nations. So when they landed at Earth-base they were received by high officials from the United Nations. After resting for a few days, and arranging the material from their trip, they set out for New York. The President of the World Council greeted them, and after a splendid reception on the first day they were told to attend the Main Council Chamber to tell the President of what they had heard from Mortvain.

When Tony had finished speaking the President sat for some time in thought.

"When does the comet get within striking distance of the Earth?" asked the President.

"The Astronomer's Department told me it would most probably be some time in July," said the Deputy President, "that is, in six months' time. They could give you the exact date if you wanted it, I'm sure."

"If we've only got six months we haven't got much time," said the President. "Have any of you young men any suggestions to make? Since you've done so much I feel you ought to be allowed to tell me just what you think about the whole thing, Mr. Martin?"

"Well, sir," said Tony. "We can either fight the Venus rockets, or we can try to knock the comet back on its path with more high explosive. The thing is, have we got enough high-explosive bombs to knock the comet off its course, and have we got enough fighter rockets to knock down their rockets? It seems to me that the fighter rockets would be easier to manufacture than the bombs. The bombs have to be so powerful that they might take years to make, whereas you can convert some of the present-day rockets into fighter rockets without any trouble at all. Take the XZ 81, for example. That was converted to a fighter rocket quite simply."

The President turned to the Deputy President.

"I think Mr. Martin's quite right. We can turn out fighter rockets quite easily, but it will take years to make sufficiently powerful bombs. What do you think about contacting Professor Mortvain again? Mr. Cabot, you spoke to him most. Perhaps you would tell us what you think about that."

"From what he said I think there isn't much chance of changing their minds. It would be a good idea to keep in touch with Mortvain, because he would be our ambassador there. But the chances of altering their minds seem to be small. Perhaps we could tell them that they won't succeed in deflecting the comet, however hard they try. And if we can drop Mortvain a better radio, then he will be able to keep in touch with us all the time. He'll be able to tell us how their plans are going on, and we can send out our fighter rockets accordingly."

"I agree with you, Mr. Cabot," said the President, "but we shall know when they're coming because the comet will only pass near the Earth once. It's most important to keep in touch with Mortvain, though, and we must get another radio up to him as soon as we can. I'd like to thank you gentlemen for all you have done. The peoples of the world are proud and grateful."

The three friends left the Council Chamber, and left the Council to their deliberations.

"That first young man, Mr. Martin, was quite right," said the President. "Either we've got to produce the bombs or the rocket fighters to counteract the danger. And with the time we've got it'll be much easier to produce the fighters. Check with the Astronomer's Department to see when exactly the comet is due to arrive here, and find out how long the supply people will be producing a fleet of a hundred fighter rockets. And tell the interplanetary boys to stop the nonsense they've been sending out over their sets, and detail one of their rockets to take the best radio they can to Mortvain."

The President's orders were carried out, and the supply department of the United Nations arranged to have the rocket fleet standing by a month before the exact date of the comet's arrival. The Astronomer-in-Chief found that it would be within striking distance of the Earth for two days, the 26th and 27th of June. By the beginning of June the greater part of the rocket fighter fleet was ready, and the original rocket XZ 81, with the same crew, was promoted to lead one of the four squadrons of rockets. They had by this time become experienced in manœuvring the rockets in formation, and had had practice with the atomic gun against dummy rockets out in space.

The radio had been delivered to Professor Mortvain, and he had elected to stay where he was. He said that the preparations of the scientists and leaders of Venus were unchanged. He had delivered the message to them to say that their rockets would never be able to deflect the comet. The President of the planetary organization on Venus had said that they would judge the strength of the Earth's forces by what they were able to do in deflecting the comet back to its original position. Nothing would make him believe that the intentions of the Earth were not firmly fixed on conquering or annexing Venus. The way for peaceful talks would only be open when the comet danger was over.

By the 24th of June all the rocket crews were ready for action at their bases. The rockets were tested as far as they could be. All telescopes were turned on the tiny speck in the sky that was the approaching comet. The radio gave news every hour of the progress of the comet, and people learnt up facts about astronomy that they had forgotten since their schooldays. On the 25th of June the rockets took off to take up positions to intercept the Venus force. Tony was in charge of his old rocket, leading the third wing of rockets with twenty rocket ships under him. As they roared up into space they came into formation as they left the attraction of the Earth behind. They swept up in the direction of the comet, to get between it and Venus to make sure that they would spot the attacking force. The size of the comet was such that it would not be easy to cover the whole area, but they expected a whole fleet of Venus rockets to come, so that they would be difficult to miss.

They were by now in their intended positions, and all the crews watched their radar screens for any suspicious movements. Ceaselessly they searched the depths of space, but saw nothing. Their eyes began to ache with the strain, and while one slept and one piloted the other watched the screen. They could see the slow shifting of the Earth, and the bright light of the Sun blazed out at them.

Suddenly the wireless came to life. One of the rockets under Tony's command reported:

"Hello XZ 81. Can see movement 11° 50′ angle of arc from centre line Earth—Venus, declination 50′ 20″. Am keeping under observation and will report further. Over."

John noted the bearing down and handed the message over to Tony.

"I'll get on to it as soon as I can to give you the line."

He quickly adjusted his instruments, and brought the stereoscopic telescope on to the bearing. He peered through it.

"There's certainly something there," he said to Tony. "What do you make of it?"

Tony moved over and looked down.

"That can't be a rocket," he said. "It's much too big. Unless there are a lot of small ones there all together."

He looked again, more intently.

"Yes, they're coming nearer, and I can see that it isn't one big rocket, but a lot of little ones. Get me all the rocket ships on the radio, John."

John turned back to the radio.

"Righto! Tony, you can call now."

"Hello Rocket Ships XZ. Deploy to your right flank, keep in extended line, and watch ahead for approaching enemy rockets."

They watched while the rocket ships moved with drill-like precision to their new formation. By now they could see the enemy formation clearly, and it seemed that they had not nearly so much control over their movements as the Earth rockets. They were coming in one bunch, and although by now they must have seen the Earth rockets they had made no attempt to alter their formation.

"Hello XZ 81," called the leader of the whole force. "You will lead the attack against the enemy rockets. Attack from above and drive them off course back towards Venus, or destroy them. Over."

Tony swung his rockets away from the approaching enemy. They were now at a distance of two hundred miles. He prepared to attack, and called to all crews over the radio:

"All rockets will wait while we make experimental run."

They turned, and XZ 81 accelerated towards the enemy. Donald had the atomic gun charged with a radar-guided atomic missile. From a range of one

The flash of the explosion and the heat kept their eyes wide open for a full thirty seconds.

hundred miles these could find their way on to their target.

"We must get as close as we can," said Tony, "but we don't quite know what they've got in those rockets of theirs."

They came closer to the leading enemy rocket; one hundred and twenty, one hundred and ten, one hundred miles.

"Ready to fire now," said Donald.

"Fire!" ordered Tony.

The atomic projectile streaked away from the rocket, and the rocket itself turned upwards and outwards away from the Venus rockets. The remainder of the Earth rockets waited a hundred miles further away. They had expected some explosion when the projectile reached the first Venus rocket, but nothing like the explosion that came. It seemed as if a whole planet had exploded. The flash of the explosion and the heat kept their eyes wide open for a full thirty seconds, and the rocket was driven with incredible velocity away out into space. Luckily for them, the explosion had merely tossed them like an acorn out into space without doing the rocket or the crew any damage other than shocking them severely. All the other Earth rockets were blown outward too. When Tony had regained control they contacted all their squadron, and looked down for the Venus rockets. But of them no trace could be seen.

By now the comet was close to them, and they moved back towards the Earth to get away from the comet's dangerous tail while its huge mass swept silently by and out into space again. They found that none of the Earth rockets had been severely damaged, but one or

The old rocket, by now quite out of date, was used as a memorial to the original rocket crews.

two of the crews had been badly shaken about by the explosion of the Venus rockets. They assumed that the enemy rockets had been carrying more than ordinarily powerful atomic bombs, and the heat of the atomic projectile had exploded the bombs carried by the enemy rockets.

When they reached the Earth again they found that Professor Mortvain had been in touch with the Venus President. The scientists there had seen the explosion and knew at once that something had gone wrong. Their force had been sent off so that the rockets would explode at the optimum moment to deflect the comet on to the Earth. They realized that their rockets must have been destroyed before they had done their job, and told Mortvain that they were willing to establish friendly relations with the Earth.

The relief expedition to take Mortvain off and establish an Earth embassy on Venus was led by XZ 81. And when the embassy was constructed there, the old rocket ship, by now quite out of date, was used as a memorial to the bravery of the original rocket crews, and round it was a memorial bearing the names; Mortvain, Duplessis, Martin, Cabot, Roper.

## ON CAPTURING A NEW SPECIES OF BUTTERFLY

"None but a naturalist can understand the intense excitement I experienced when at last I captured it. My heart began to beat violently, the blood rushed to my head . . . so great was the excitement produced by what will appear to most people a very inadequate cause" —Wallace.

# The Science of Sprinting

O. B. TYMMS

WHEN we were very young we were taught to walk and very soon afterwards we taught ourselves to run. Looking back now we cannot imagine a time when we could not both walk and run, and we think that we can do both now sufficiently well for ordinary purposes. This is probably true, but it is also true that we would not be satisfied with a bicycle or any other machine which merely worked sufficiently well; we should want it to do better than just that. Scientifically we say of a machine that we want it to work as efficiently as possible. That, then, is what we should also require of the human machine, our own body.

On a bicycle, we usually have three or four gears which we use in order to make the most efficient use of the bicycle, or more exactly so that we can use as little energy as possible to cover a certain distance. We can only talk about working as efficiently as possible when we are overcoming an obstacle, for instance, climbing up a flight of stairs or digging a hole, when the time to be taken does not matter. As an example, if we want to climb a flight of 78 stairs which is 40 feet high, using as little energy as possible, the best way is to climb up steadily taking about 2 minutes. Of course, this is very slow; you would probably climb up the stairs two at a time. But you would be concerned with climbing to the top as quickly as possible and not with saving energy. That is exactly what concerns us when running a race.

We want to cover the ground as quickly as possible without worrying about the energy we use; to win a race we have to use up all our energy so that we are exhausted at the end of a race. However, although we want to use all our energy, we do want to use it in the best way possible.

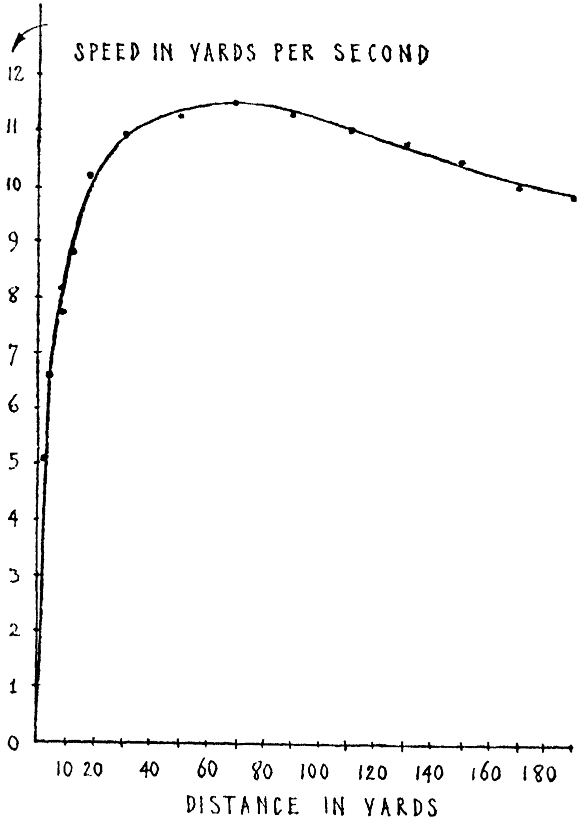


Fig. 1. How a sprinter's speed changes with distance.

One point which we noted about climbing the stairs applies also to running; we must try to keep the same speed all the way. If Roger Bannister could run a mile at the same speed all the way, he would certainly improve his fastest time of 4 mins. 9·9 secs. in New Zealand in 1951 and might equal Wooderson's record. This, of course, is true for breaking records, but it is not usually the best way to win a race. Here you have to take into account the other runners and you must adjust your speed accordingly. Again, it is not so important when sprinting because usually you run as hard as you can all the way.

In this article, we shall call races sprints when they are less than 440 yards. We shall see first how far we must run before we reach our top speed. Some tests were carried out at Cornell University, U.S.A., some years ago to obtain this answer. A sprinter ran 200 yards, carrying around him a magnetized girdle which did not impede his running. At the side of the track were placed at fixed points sensitive galvanometers. By this means, an accurate record could be made of the time when he passed each of these check points. The speeds measured in this way are shown in Fig. 1. We see that the greatest speed occurred about 80 yards from the start and then he slowly but steadily lost speed after that point. The greatest speed reached was about 11½ yards per sec. or 23½ miles per hour.

Now let us look at the time he took to travel successive 20-yard stages:

| Distance in yards: | 0–20 | 20–40 | 40–60 | 60–80 | 80–100 | 100–120 | 120–140 |
|---|---|---|---|---|---|---|---|
| Time in seconds: | 2·760 | 1·835 | 1·785 | 1·745 | 1·760 | 1·810 | 1·855 |

This shows how long the first stage takes compared with the later stages and therefore how important a quick start is. We must study a little more closely the action of running and how it affects the start in particular.

If you stand still with your feet together and lean forward so far as to lose your balance, you automatically put one foot forward to save yourself from falling. This is precisely what happens when you run. You are continually saving yourself from falling forward. This allows your weight, which is a force acting downwards, to act so that it helps you to move forward. This, and the force with which your foot pushes off from the ground (the frictional force) are the two main forces acting at the start of a race. Later the momentum due to the speed which you have already gained carries you forward and provides a large part of the motive power; the frictional force remains important and the falling effect becomes less important.

This effect of falling forward is, as we have said, most important at the start and for that reason we must begin the race with our body sloping well forward. In fact we shall want to be sloping forward slightly all the time; at the start we need the angle to be about 35° to obtain the greatest effect, whereas later 75° will be all that is necessary. It is interesting to learn that Jesse Owens at the time of the Olympic Games in 1936 was still being told by his trainer that he ran too upright although he won easily both the 100 and 200 metres races. In order to obtain this initial slope, we must of course crouch down at the start and shoot forward head first. Obviously we want to obtain as great a push off as possible and so we use either starting holes or blocks. In either case the surface we push against must be perpendicular to the direction in which we wish to propel our body. This means that they must slope at 55° or more to the horizontal. Since we shall not attain our greatest speed until about 80 yards, we shall not want to increase our angle of slope to 75° until then. This is the ideal; in fact we shall probably reach our greatest slope about 30 yards from the start. This is illustrated in Fig. 2. Remember, of course, that we are considering only sprinting and that we must modify our ideas for longer races.

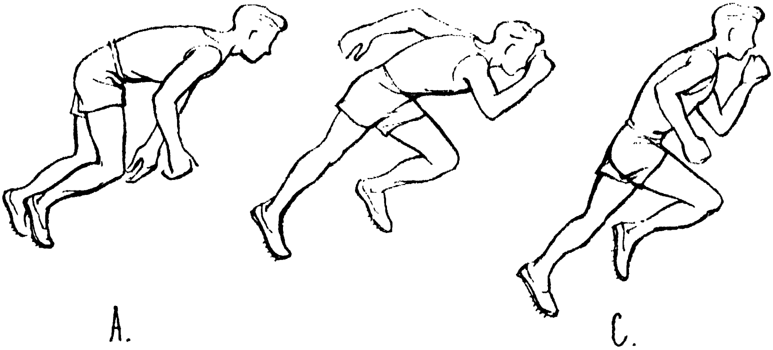


Fig. 2. Change of body slope during a sprint; (*a*) just after the start; (*b*) at thirty yards; (*c*) at seventy yards.

The frictional force, as we have seen, plays an important part throughout the race and even more at the beginning than later. We must therefore touch the ground as often as possible at the start. A tall sprinter such as Harold Abrahams takes a stride of nearly 8 feet when travelling at full speed, but his first stride should be short, only about 3 feet. This will give a greater total frictional force in the first few seconds when we are lacking momentum. Because of the frictional force, throughout the race we want to move our legs as quickly as possible rather than to take long strides. Harold Abrahams was the first to pay great attention to this.

He decided that by speeding his leg movement and slightly shortening his stride he could obtain one more stride in a 100 yards race. Striding has its value in longer races but in sprints the legs must work quickly and the action must be one of chopping down the leading foot as quickly as possible.

For finishing a race, a drop finish used to be favoured. The idea was to throw forward the chest to breast the tape, but although this appears to gain inches, it is not efficient because it provides a slight check to the smooth movement of the body which is just sufficient to cause it to lose speed. The method favoured today is to continue to run naturally right through the tape. The key here being, as it should be throughout the race, to relax all muscles which are not actually working. This is particularly true of face muscles, which should not be contracted.

We ought now to think of the arm action. It is necessary, of course, to swing the arms as we do when walking to keep our balance. It is even more important to swing them to give greater drive to the legs. But what happens to the arms must not affect the shoulders and body. These should remain in the same direction throughout the race.

If we were to pay attention to all these points, would we then with training be capable of equalling La Beach's world record of 10·1 seconds for the 100 metres, or is there a limit for each individual? Unfortunately the latter is true and we shall now see what governs this limit. The energy we have is controlled by the amount of oxygen which we use. Our use of oxygen is rather like our use of money. If we want to spend more than our income, we have two alternatives. Either we save up beforehand or we go into debt. Running a race we choose the second alternative; we use our income of oxygen and a lot more and so go into debt. The result is that at the end of a race, we have to puff and pant to pay back the debt to our lungs. The greatest income of a healthy man is not more than 4 litres of oxygen a minute and the greatest debt which can be incurred is not more than 15 litres. Thus in short races, which we are considering, the debt is really more important than the income. In longer races the reverse is true, and this explains why some boys are good sprinters but not very good at steeplechases and vice versa. The oxygen requirement can be converted into energy for any person and then into speeds. We can thus work out the greatest speed which a runner could attain over any given distance.

Experiments were carried out some years ago on a Cambridge Blue. It was found that he was able to incur a debt of 13·7 litres and that his intake was as follows:

| | | | | |
|---|---|---|---|---|
| Time in minutes - | 1 | 2 | 4 | 10 |
| Intake in litres - - - | 1·7 | 4·9 | 11·8 | 32·7 |

This meant that in one minute he had at his disposal 1·7 litres income and 13·7 litres debt, so that he could spend out at the rate of 15·4 litres per minute; converted into speed this meant 480 yards per minute. For two minutes, his income was 4·9 litres and his debt 13·7, so that he could spend at the rate of 9·3 litres per minute, which meant a speed of 440 yards per minute. For 4 minutes his spending rate was 6·4 litres per minute and his speed therefore 387 yards per minute. For 10 minutes his spending rate was 4·64 litres per minute and his speed 348 yards per minute. His fastest time was known over various distances and these were compared with those computed in this way. The results are shown in the table.

| Distance | 300 yards | 440 yards | $\frac{1}{3}$ mile | $\frac{1}{2}$ mile | 1 mile | 2 miles |
|---|---|---|---|---|---|---|
| Calculated time . . | 33·3 secs. | 51·5 secs. | 1 min. 12$\frac{1}{2}$ secs. | 2 mins. 1 sec. | 4 mins. 41 secs. | 10 mins. 12 secs. |
| Fastest recorded time | 34 secs. | 51·4 secs. | 1 min. 15 secs. | 2 mins. 2 secs. | 4 mins. 40 secs. | 10 mins. 10 secs. |

This seems too good to be true and probably if the experiment were repeated with someone else we should not get quite such a good result. It is, however, sufficiently convincing to show that if we could measure for a runner in training his possible oxygen debt and also his oxygen income we could easily say what race he ought to run and how fast he is likely to complete it.

There are other very interesting questions to be raised here but which cannot be dealt with fully. Obviously if we try to run in a mountainous district, we shall not travel so fast because there is less oxygen, but if we could increase the oxygen supply artificially, what would be the effect? Breathing pure oxygen, our income might rise by about 50 per cent but our debt would not be increased. There is therefore little to be gained by sprinters but longer distance runners would benefit enormously.

## ANSWER TO THE PROBLEM OF THE FOOTBALL FAN

(p. 204).

Trains to Tackleham left at 2.00, 2.10, 2.20 . . ., and trains to Kickham at 2.01, 2.11, 2.21. . . . The probability of his catching a train to Tackleham was therefore 9/10, to Kickham 1/10.

# Racing Car Engines

JAMES STAFFORD

THE first motor-car appeared on the scene at the end of the last century, and because of its resemblance to the earlier horse-drawn vehicles it was called a "horseless carriage". These first cars, very crude by modern standards, were propelled by petrol engines whose principle of operation was the same as that in use today. Mostly, the engines were of one cylinder of large size, instead of the multi-cylinder units which are in use now. But the important thing to remember is that the basic principles of the very early car engines, present-day petrol motors, and racing engines are the same. The differences are of degree only.

Before we consider the details of the engine itself it is desirable to understand some of the basic theory which makes the unit work at all. The petrol engine is termed a heat engine and this means that, simply, it works by taking in a quantity of air into its cylinder, heating it, and using the rise in pressure to force a plunger or piston down, and this piston is connected by a series of links—the gudgeon pin, connecting-rod, etc.—to the output or crankshaft. The cycle of operations of a petrol motor can be of two distinct types—two-stroke and the four-stroke—but in this article we shall only consider the latter. In this case the cycle is as follows:

(1) *Induction.* The piston starts at the top of its stroke and, descending the cylinder, draws in a quantity of petrol/air mixture (which has been provided by the

carburettor), through the inlet port or manifold, past the inlet valve, and into the cylinder.

(2) *Compression.* When the piston reaches the bottom of the induction stroke, the inlet valve closes, and the piston rises up the cylinder again, with both inlet and exhaust valves closed, compressing the mixture which it has just drawn in.

(3) *Power.* At the top of the compressing stroke a spark is introduced into the cylinder by means of a sparking plug, and ignites the charge. It is important to remember that the charge does not explode, but burns very rapidly indeed, causing a sharp rise in temperature and pressure, which forces the piston down again to the bottom of its travel in the cylinder. This is the actual power which the engine gives; the other three strokes in the cycle are only necessary evils.

(4) *Exhaust.* It is inevitable that some residue remains in the cylinder after the firing stroke, and these burned gases are expelled from the cylinder, as the piston goes up on the exhaust stroke with the exhaust valve open, allowing the cylinder to be cleared to atmosphere ready for the whole cycle to begin over again.

It is clear that, in the four-stroke engine, the piston is only acted upon once by the source of power, and to get this, the crankshaft must make two revolutions. In a twin-cylinder the turning of the crank is more uniform with one power stroke in each revolution, and this advantage increases as the number of cylinders is increased, and that is why the majority of car engines have at least four cylinders, and some touring cars have as many as twelve.

The theoretical amount of mixture which an engine draws in depends on the bore of the cylinder, and on the distance which the piston travels (or stroke). Actually the amount drawn in, in fact, is always less than the theoretical maximum, which is called the Swept Volume of the engine and is usually measured in cubic centimetres (c.c.). This is why we refer to a "500-c.c." or to a "2-litre" engine.

Having drawn in the charge, the piston now compresses it into the combustion chamber space and it is the relative size of this space which determines the "Compression Ratio". It is not usual to find engines operating on petrol with a compression ratio of more than 8 : 1. Above this figure it is necessary to use other kinds of fuel—benzol, alcohol, etc.—either added to the petrol, or as a straight fuel. The compression pressure determines, to a very large extent, the power output of a given engine—the higher the C.R. the greater the power output, other things being equal. In the normal unsupercharged engine, the pressure of the atmosphere (14·7 lb./sq. in.) is used to force the mixture into the cylinder, and this fact limits the compression pressure. This does not apply to the supercharged unit.

The power which is developed is measured in horsepower, and this is a scale of the rate at which the work is done. There are two "kinds" of horse-power—Indicated (that is, the calculated power available neglecting losses), and Brake (which is the power actually available to do work of some sort). So we speak of an engine "developing one hundred brake-horse-power" or "100 b.h.p." It is rare to find touring car engines which give more than fifty b.h.p. per litre, and most mass-produced cars give much less than this figure.

Apart from the compression pressure of the engine, the other main factor in the output of power is the speed at which the engine operates. Other things being equal, a given motor will give twice as much power at two thousand revolutions per minute as it will give at one thousand. The limiting factors in speed are largely mechanical and depend on the strength of the components. Here one is concerned with lightness on the one hand and with strength on the other. If a connecting-rod, for example, has to move very quickly, the lighter it is the better, since less energy is lost in overcoming its inertia, but when the operating pressures are high, so must be the strength of the rod. During the past twenty years it is the improvement in the strength of materials which has made the very high power outputs of today possible.

A third major factor in power output is the method of inducing the mixture. This is either forced in by atmospheric pressure and the engine is termed "normally aspirated", or it is forced in by some form of pump or supercharger, when the engine is described as "blown". With a supercharger the initial pressure in the cylinder, before compressing starts, is above that of the atmosphere in some cases by as much as 30 lb./sq. in., and so the effective compression ratio is increased and the power available from the engine increases too. It must be remembered, however, that a considerable proportion of the increased power will be needed to drive the blower or supercharger.

In the racing engine everything is more highly stressed than in the touring car engine; all the components are designed to be as light as is possible bearing in mind the job that each has to do. For this reason, the reliability is much lower, in most cases, than in touring cars, and the amount of attention required to keep the engine at the peak of its efficiency is considerable. The ideal would be for the engine to perform right through a season's racing without any attention at all, but in fact many racing car engines have to be stripped down to the last nut and bolt after every race to ensure that everything is as nearly perfect as is possible for the next race. There are so many hazards in racing that the element of doubt must be reduced as much as possible by the mechanics.

In road performance it is clear that more power is needed to accelerate a heavy thing than something which is lighter, and therefore the weight of a racing car must be kept to a minimum. As the engine is usually the greatest single mass in the car its weight is of paramount importance. Whereas in the touring car many of the castings are in cast or malleable iron, in the racing engine aluminium alloys must be used, and, where possible, materials like magnesium, because of their lightness. This makes the racing engine a rather more expensive unit to produce, and in addition the greater accuracy demanded in many of the parts also makes them more costly. Racing is a very expensive matter, as many have found. An engine run up too high on the indirect gears may be easily "burst" and if the damage is extensive a whole new engine must be found.

Now we must consider mixtures and fuels. The ordinary petrol which is purchased from a pump will perform in engines with a compression ratio of up to about 8 : 1. For higher ratios, it is usual to mix varying percentages of pure benzol with the petrol to improve the anti-knock value of the fuel and this will allow ratios up to about 10 : 1 to be used, depending on the actual engine design. For still higher ratios it is usual to employ an alcohol such as methanol, as, in addition to its qualities as a fuel, there is a considerable advantage to be gained from its latent heat of vaporization, which, in effect, assists in cooling the engine. During and since the 1939–45 war, there have been great advances in the production of special fuels which are suitable for supercharge pressures and compression pressures which would have been impossible before the war. A factor which greatly affects these high compressions is the presence of local hot-spots in the combustion chamber. These may arise if the wrong grade of sparking plug is used, by getting over-heated valves, from an incorrect waterflow in the jackets round the head and upper part of the cylinder wall. Cooling, therefore, is very important, and it is effected not only by the actual water-cooling system, but by the considerable amount of heat that is taken up in the lubricating oil from other parts of the engine. Many racing engines are fitted with radiators to cool the oil, in much the same way as a touring car radiator cools the water.

While discussing fuels, a word should be said about the induction and exhaust ports. It must be evident that with an engine running at, say, four thousand revolutions per minute, the gases in the inlet and exhaust ports are each started and stopped two thousand times per minute. In addition, the gases will be flowing through the ports, at the appropriate times, as well. This means that the velocity of the gases is extremely high in the ports, and so the smoother the surfaces of the ports the less will be the drag on the gases and the greater will be the "volumetric efficiency" of the engine. In all racing engines the ports are so highly polished that the heads of the valves appear to have been chromium-plated, but, naturally, they have not been so treated.

People take part in motor racing for several reasons. Many individuals race for the love of the sport. Companies do so, or have done so in the past, to gain technical data to help in the ordinary problems of production. Countries race to enhance their national prestige.

In the years before the war, many private racing drivers raced cars which were modified versions of some production unit. This is a relatively inexpensive form of amusement, but the performance of such cars can be very high, as, for example, that of the German racing cars which were so successful in the years immediately before the war. These German teams—Mercedes-Benz and Auto-Union—were heavily subsidized by the German government, and had large internal organizations to carry through their racing programmes. In one case, there were several hundred men permanently engaged in racing, and in addition the services of any other department of the firm could be made over to the Racing Department on demand.

Racing engines are governed in size by what is known as the International Formula. At the present time this formula, for the faster cars (Formula I), lays down that the engines shall not exceed 1½ litres in capacity (swept volume) and that they may be supercharged. The formula now in existence lasts until January 1st, 1954.

When one considers present-day and future performance, perhaps the most interesting engine is that installed in the British B.R.M. car. Its basic design differs very little from that which has been adopted for many years; it has the hemispherically-shaped combustion chamber with inlet and exhaust valves inclined, and the sparking-plug mounted centrally in the cylinder-head. By referring to the plate (facing page 199) of the off-side of the engine unit it will be seen that the crankshaft, the tip of which just protrudes on the right-hand end of the engine, is mounted high up. The shaft itself is made in two halves which are fixed together at the centre by a duplex gear. Two connecting-rod big-end bearings are mounted on each crankpin, and in this way each half of the crankshaft corresponds, simply, to a normal four-cylinder crankshaft.

The drive for the camshafts will be seen in the centre of the right-hand bank of cylinders. The cylinder-heads themselves, four of them, correspond rather closely to a normal four-cylinder head, having two camshafts—one inlet and one exhaust. In fact the whole engine may be considered as four four-cylinder engines coupled together. Each valve is closed by twin hairpin springs. Single sparking-plugs are provided for each cylinder, and the ignition is by four coils and distributors—it is considered that coil ignition is more suitable than magneto ignition for very high speeds. At peak revolutions the B.R.M. ignition equipment is delivering about 100,000 sparks per minute. The two-stage centrifugal supercharger is mounted on the studs shown on the right-hand end of the plate (facing page 199), and this is driven by a shaft mounted in the lower part of the crankcase and running faster than the engine speed. The supercharger, fed by normal carburettors, itself feeds the sixteen cylinders by a branch manifold system. One of the two water-pumps will be seen on the lower part of the centre of the diagram, and these circulate the cooling water round the cylinder-heads, block, and water radiator. Lubricant is supplied under pressure to the main and big-end bearings by two gear-type oil pumps which are mounted near the water-pumps. The engine is constructed on the dry-sump principle, and oil is scavenged from the lower part of the crankcase by two scavenge pumps which return the oil to the oil tank. Two large-size oil filters are provided, and the end of one of these can be seen protruding from the lower part of the crankcase. Why is it that the expected power output from the B.R.M. engine should be so large? We have tried to show in the foregoing that the power output of an engine depends on the speed revolution, and on the boost-pressure in the case of a supercharged engine. The 12,000 r.p.m. of the B.R.M. crankshaft is, even by modern standards, high, and, in addition, the pressure in the induction manifold generated by the two-stage centrifugal supercharger can be higher than in any other engine at present.

The design of the cylinder-heads themselves incorporates very liberal water-cooling pockets, and there is virtually a complete absence of any hot-spot in the whole of the combustion chamber which can cause pre-ignition of the compressed charge.

It may be that in the years which lie ahead, the development of supercharged piston-type engines will advance to the stage where we can secure a power output of more than 500 b.h.p. per litre. It may be also that the gas-turbine type of power unit will be used extensively for road vehicles. In any event we may expect to see piston-type engines and gas-turbine engines competing together in Grand Prix events on the race-tracks of the world in the not too far-distant future.

# The Universe We Live in—Theories Old and New

J. P. GRANTHAM

In very ancient times, although great interest was shown in the stars, the universe was explained in irrational ways. There would be an official mythology whose attendant priesthood told the people what was so and how it came to be so. Astronomy and other sciences were pursued, and many surprisingly accurate observations were made, but the explanations had to fit in with the current mythology. It is worth while trying to understand how present-day scientific reasoning ever came about, for it is only recently that man has accepted rational explanations for the observed happenings in the universe. We are so used to looking for rational causes for observed effects, that it is hard to realize that for thousands of years most civilized men never even considered such an outlook. During this long period occasional attempts at rational or semi-rational cosmology were made and, even if they may seem amusing when compared with our present-day ideas, they were great advances.

In Ionia, in the sixth century B.C., a race of severely practical men was developing; they were successful merchants who had no time for ancient myths and built up a philosophy based on every-day experience. These merchants were the ruling aristocracy, and their prosperity depended upon the development of new practical ideas, so that a practical philosophy was necessary to their livelihood. One of these gentlemen, called Thales, had a number of new ideas. He picked up various mathematical and astronomical facts from the Egyptians in the course of business trips, and proceeded to sort out and rationalize them. He provided proofs for the Egyptian geometrical theorems, and, by getting down to first principles, extended the geometry developed for measuring and marking out fields into a method of triangulation at sea. In Babylon and Egypt water was literally on everyone's doorstep, and much time and effort had to be spent in removing it from agricultural land. It was only natural that people decided that in the beginning all was water. The Babylonians had a creator who floated about on a rush mat, and then made a lot of dirt, piled this up round his mat and so made dry land. Now Thales made an important change to this theory; he replaced the creator by natural causes, like the silting up he had observed in the Nile delta. The basic thing was still water, which might itself be the work of a creator, but there must be a natural explanation for all later events. He said that the Earth was a flat plate floating about on this general mass of water, and that this huge sea extended over our heads, a little falling out at times and producing rain. The sun and the stars floated round on this sea.

After Thales came Anaximander, who produced a more complex explanation of the universe. He said that there were four basic elements, earth, water, mist and fire, in this order of density. To start with they were in layers with the heaviest at the bottom. The fire heated the water, evaporating it and causing earth to appear in places as dry land. As this process went on, more and more mist was formed and the mist pressure became very high, so that eventually there was an explosion. The outcome of this explosion was a number of fire hoops circling the Earth, each hoop enclosed in a tube of mist. Stars are this fire, seen through holes in the mist. This whole system was not the complete

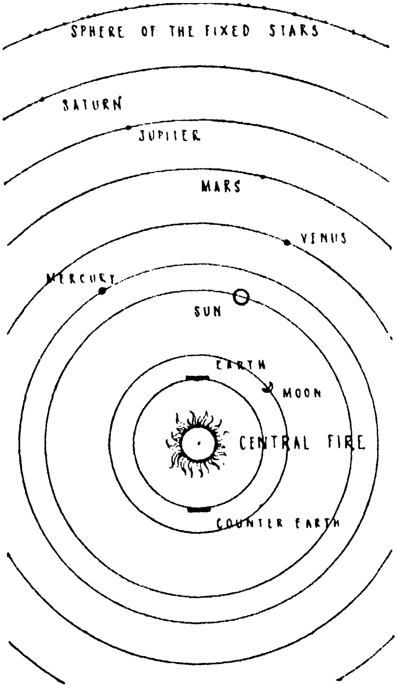


Fig. 1. The Pythagorean theory of the universe (not to scale).

universe, but was suspended in space in some sort of equilibrium with everything else. Other philosophers followed Anaximander in Ionia, each one adding to the ideas of his predecessors. The main combined effect was to throw off the cloak of mystery that had surrounded cosmology.

Pythagoras, whom we usually associate with right-angled triangles, was the founder of a religious tradition and a politician as well as being a mathematician. He, also, was an Ionian by birth, but he emigrated to Southern Italy. He founded an important and influential philosophy which was excellent (from the scientific point of view) in that everything was explained mathematically, but which suffered from being married to religious and social systems. Pythagoras thought that the number of moving bodies in the sky *must* be ten—to him a mystical number. The Earth, Moon, Sun, Mars, Venus, Mercury, Jupiter, Saturn, and the "sphere of the fixed stars" made only nine. The "counter-Earth" was therefore invented to fill the gap. All ten objects, including the Sun, were thought to rotate round the "central fire", which was underneath the Earth.

However, the simple Pythagorean ideas, based entirely upon scales of numbers but including great advances in mathematics, grew eventually into the complex system devised by Ptolemy that lasted more or less intact until the sixteenth century. The unfortunate outcome of Pythagoras's philosophy was the acceptance of the stars and planets as deities to whom natural science was not applicable. As controlled experiment and observation began to play a more important part in science, it was found that the Sun, Moon, and planets appeared to move at varying speeds in various directions; this, it was asserted, was not as it should be, for divine beings would never move in a disorderly manner. A major problem for the astronomers was to explain how the planets moved with perfect order and yet appeared not to do so.

Some of Plato's followers provided an answer—that the planets' motions were combinations of a large number of circular motions. Some men, who had the audacity to question the approved line of thought, were said to be explaining the divine in earthly terms and were promptly imprisoned, banished, or otherwise removed from the scene. Aristotle followed in the tradition. He thought that there were fifty-five concentric spheres revolving round the Earth and that the planets and stars were fixed to these spheres. Outside the first sphere, to which was affixed the Moon, only this revolving movement was allowed; between it and the Earth other movement could take place. Thus, the idea that a different state of affairs existed in the heavens from that on the Earth was perpetuated. Aristotle was a sufficiently great scientist to allow other opinions and to say that they should receive due regard; he also insisted upon observational evidence to corroborate his own and others' theories. We can see the dawn of the superiority of observation and experiment over myth and social necessity.

Peoples other than the Babylonians, Egyptians, and Greeks were interested in astronomy in ancient times; for instance, we now know that the Aztecs held comparatively advanced ideas some centuries before the Spanish conquest. It was the Greeks, however, who had the greatest effect on later scientists. The Arabs made some notable advances on the earlier Greek theories, but they little influenced later European development. The Hebrews' observational astronomy had an undeservedly great effect in later times owing to the influence of the Old Testament on those who took it to be literally true in every detail; this procedure was especially unfortunate as the translations were often inaccurate and few parts of the Bible were available in their original forms.

The disturbing effects of international and civil wars, and the reactionary attitude of the Church, throughout the Dark Ages, virtually halted scientific advance. In the Dark Ages, it has been said, it was too dark to see the sky. One of the first figures to emerge from the darkness in the fifteenth century was Copernicus, who revived an old Greek suggestion that the Earth moved round the Sun. In the following century, Galileo, who was born in Tuscany, made his great stand against the Church; he was too well known and respected for the Church to be able to silence him effectively. Galileo designed and constructed a telescope, using Dutch information on lenses. As well as discovering many new stars and some satellites of the planets, he inferred from his observations of the heavens that the Earth was round and moved around the Sun. The Church said that this was wrong, one of its arguments being based on an Old Testament story that God stopped the Sun in its path over the Earth in order to influence the course of a battle. Galileo was persecuted for his beliefs, but he won for later generations of scientists the right to question current ideas and he was the founder of modern astronomy.

Freer than ever before from the shackles of prejudice, science moved forward rapidly. In about another hundred years' time, Newton had propounded his laws of motion and gravitation to apply to all bodies on the Earth or in space. When these laws were applied to the planets they appeared to work; some time later, slight deviations from the calculated orbits of the planets were observed and it was shown that these deviations could be explained by the presence of another planet of a certain size on a certain orbit. The position of this planet (Neptune) was calculated so accurately that when a telescope was pointed in the theoretically correct direction the planet was seen. Newtonian physics worked so well that when, in recent times, it was shown to be inaccurate when applied to very great distances, masses, and velocities, physicists were reluctant to abandon it. Looking back, we can see that Newton's laws were approximations to the laws which hold for the observed universe, and that the errors involved in using Newton's laws under most conditions on the Earth are negligible. We do not have to abandon Newtonian physics in the way that we have abandoned the Greek theories, but extend it to cover broader fields. We still use Newton's laws to calculate events on the Earth and we still appear to get the right answers. Most modern scientific work is impartial and controlled within specified limits, so that it usually is true as far as it goes. When the occasion or genius arises, the work is extended. This extension may open up a new field, but it is seldom that new theories are not based on the background of a mass of earlier work. Even in cases where the old idea is proved to be wrong, we often continue to use it, for convenience, in situations when we know that it will give us very nearly the right answer.

Early in this century Einstein and Minkowski introduced the special and general theories of relativity, which made great changes to our ideas about space and time in the universe. There are very few occasions when we must remember relativity on the Earth, but we must always do so when we look out into space. The important point about the principle of relativity is that the rules apply wherever you are in space and time; this enables us to apply knowledge gained from observations made here and now to distant parts of the universe either now, a long time in the future, or a long time ago. In so-called classical space and time, a rigid rod had the same length in whatever direction you pointed it and however you moved it about in space or time. The principle of relativity states that the rod only has the same length when referred to a system that is stationary relative to the rod. The rules tell us how to measure the rod with reference to systems moving at uniform speed relative to the rod, and also to systems accelerating relative to the rod. When we remember that bodies in space are often moving relative to each other at vast speeds, and that they must have relative accelerations due to gravitational forces, it is clear why we must remember relativity when examining the universe. A further important point is that time is only relative, and not absolute, so that we must be careful how we measure time. What Einstein does is to define an event in space-time in four dimensions, and to tell us how to refer to another event relative to the first one. These four dimensions are not three lengths $x$, $y$, $z$ and a time $t$ in the sense that we imply when referring to a point in a solid body on the Earth and then looking at a clock and saying it was there at three minutes past ten this morning, but four space-time dimensions $a$, $b$, $c$, $d$. Think of a sphere on the Earth; you define a point in it by three co-ordinates $x$, $y$, $z$ and there is no doubt about what you mean. Now try to define the point in the sphere by two co-ordinates $x$, $y$ and you cannot give a clear picture of what you mean. Two co-ordinates will only do for defining a point in a plane. It is just as impossible to define an event in space-time by three co-ordinates.

The modern astronomer has new tools as well as new physics at his disposal, one of the newest tools being the radio telescope. A radio telescope has a large mirror or radio-frequency lens to focus radio waves, just as a telescope or searchlight uses mirrors and lenses to focus light waves. It is, in fact, a type of radio aerial which can be made to give such a narrow beam that it can be used for accurate determination of direction. The larger the aerial, the narrower the beam and the greater the amount of energy intercepted by the aerial. Light waves are similar to radio waves but of much shorter wavelength and our mirrors and lenses for light and radio work in much the same ways. The one great difficulty in making a radio telescope that is comparable in directivity and energy-catching power to a light telescope is directly related to the difference in wavelength between light and radio waves. The directivity and catching power of a mirror or lens depend upon its size in wavelengths, so that even the huge 220-foot diameter mirror of one radio telescope in Britain is small in wavelengths compared with the mirror of a light telescope. There are two kinds of radio telescope; one having a sensitive receiver connected to the aerial and so being directly comparable in its function to a light telescope, the other having a transmitter and receiver

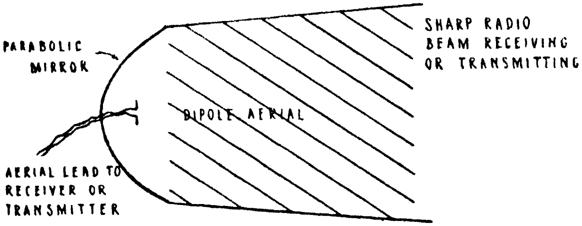

PARABOLIC MIRROR
SHARP RADIO BEAM RECEIVING OR TRANSMITTING
DIPOLE AERIAL
AERIAL LEAD TO RECEIVER OR TRANSMITTER

Fig. 2. A radio telescope aerial—the dipole aerial is at the focus of the parabolic "mirror", which may be made of wire mesh.

and working like a radar set. The second type transmits a short radio signal at an object that will reflect radio waves and, by measuring how long it takes for the signal to return, shows how far away is the reflecting object. The use of this type is limited to objects that are comparatively close, for the signal returning from distant objects is too small to be detected.

Meteors have always interested astronomers and the radar type of radio telescope is used for investigating their movements. Most meteors are not bright and cannot be seen with ordinary telescopes; also, as meteors are transient phenomena, there is not time to wait until it gets dark or until clouds clear away and many meteors remained completely undetected.

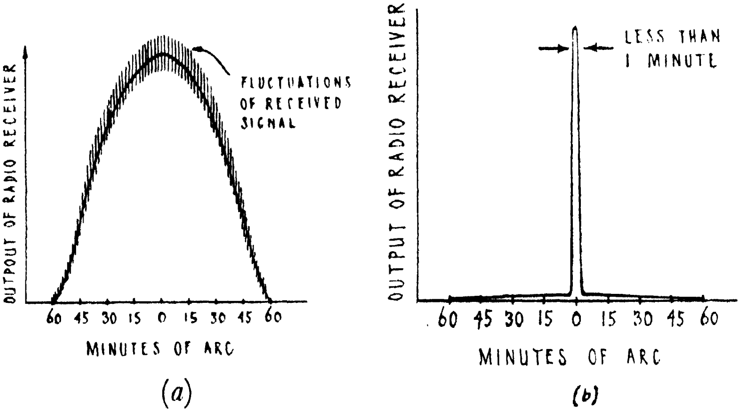


Fig. 3. Radio telescope pictures. (*a*) Picture obtained as a radio star passes across the aerial beam; (*b*) the kind of picture we would expect if the radio beam were as sharp as the beam of light from a star.

When a meteor enters the Earth's atmosphere, the usual speed being about 100,000 m.p.h., it disintegrates as it passes through the air and most of its motional energy is turned into heat. A little of the energy, about

1 per cent, is turned into light and a very little, about one-hundredth of 1 per cent goes into electric energy in the air and disintegrated meteor. This latter process is called ionization and it consists of giving electric charges to the molecules; if a radio wave reaches such an ionized meteor trail, a little radio energy is transmitted back again. The ionized trail of a meteor is about 5 miles long and will give us echoes on the radar type of radio telescope. Using this new technique, we have found out that about 300 million meteors enter the Earth's atmosphere every hour, most of them burning away by the time they are 60 miles from the Earth. We can see about five an hour with the naked eye, and usually call them shooting stars. As you will probably have noticed, there are many more shooting stars than usual at certain times of the year; this happens when the Earth passes through a cloud of débris in space. These clouds are quite common in the universe, and a number lie on orbits round our Sun. The bands of débris are quite wide, extending for about 50 million miles; one, newly discovered, is about 100 million miles wide and rather denser than normal.

The other type of radio telescope, with a large aerial and a sensitive receiver, is used for the observation of radio waves reaching us from space. Only waves with wavelengths between twenty metres and one millimetre reach us in useful strength, as outside this band the energy is absorbed in our atmosphere. It has been found that there are a large number of things in space that emit radio waves; we cannot yet say definitely what these things are, but it is reasonable to assume from the evidence we have that they are stars or something intimately connected with stars. Radio waves have been detected that come from another galaxy, and it is probable that all galaxies contain these radio stars; the radio waves come from the great nebula in Andromeda, which is 750,000 light-years away. One light-year (the distance travelled by light in a year) is used as a convenient measure of distances in the universe; the nearest stars are about 3 light-years away, or about 15,000,000,000,000 miles. The former is a much easier way of writing down the distance. Although such distances are beyond our imaginations, they can mean something to us. We are quite used to reading maps of the world which are scaled down by 100,000 times; a globe map of the world scaled in the ratio of a mile to a light-year would be one ten-thousandth of an inch in diameter. It is just possible to imagine this small size, as it is the thickness of a thin piece of paper or somewhat thinner than tissue paper. The Earth is about the biggest thing that we know at first hand—think of it in terms of how long it takes to fly round it in a fast aeroplane or sail round it in a ship. We can, therefore, just imagine a light-year; we scale up a mile in the ratio of the biggest thing we can imagine to the smallest. If we made our minute globe, the Sun would be about one inch away and the size of the dot made with a sharp 3H pencil. Returning to radio stars, present theories are that they may be young stars that are not yet hot enough to emit much light, for we know of stars so hot that they emit X-rays instead of light waves; or they may be radio-emitting clouds associated with ordinary stars. In any case, it does seem as though invisible stars extend over areas of space much larger than those occupied by visible stars, so that our old estimates of star density in a galaxy were too small.

Our Sun emits radio waves that we can detect, although it is not a powerful transmitter, but it is so much nearer to us than other stars. Regular observations are made of the Sun's radio emission, which has been found to vary when disturbances occur on its surface. We can see about 2000 stars at any one time with the naked eye, 1,000,000 with a small telescope, and upwards of 100,000,000 with a large telescope. Some parts of the galaxies, including our own, are obscured by great clouds of dust, but we are learning a little of what lies beyond these clouds by using radio telescopes.

With all these new devices at his disposal, the modern astronomer has learned a lot about the universe. The very latest observational evidence is always incomplete, so that you will realize that some of the latest theories have not yet been proved to everyone's satisfaction and that in some cases there are opposing theories. In order to avoid confusion, I shall give you one set of views only, but do not forget that a responsibility of being up to date is that you should be especially ready to listen to other points of view.

All of space is filled with a very rarefied gas consisting mostly of hydrogen. This gas is so rarefied that there is only one atom to a cubic inch. Due to local disturbances in this gas, eddies and so forth, a form of condensation or concentration occasionally occurs, and the result is a cloud of less rarefied gas. One cubic inch of this gas contains about 100,000 atoms, which is still very thin by earthly standards. It is probable that this cloud would at first be a thin rotating disk, 50,000 to 100,000 light-years in diameter and about one-tenth as thick. Local irregularities and gravitation cause this gas to condense into clouds and then into stars. We call the gas the inter-stellar gas, and it can be detected by observation from the Earth. The more rarefied inter-galactic gas cannot be detected directly with any instruments that we possess, but you will see later why it is that we think it exists. As the condensation and contraction process involved in the birth of a star progresses, the temperature in the middle of the star increases until nuclear transmutation of hydrogen into helium takes place. You probably know that the nucleus of a hydrogen atom contains one proton; if four protons are combined we obtain the nucleus of a helium atom and also liberate some energy; this process is called nuclear transmutation and it only occurs at very high temperatures. When this happens in the middle of our new star, the energy released begins to compensate for the energy lost from the surface by radiation, and a stage is reached when the star is in equilibrium and ceases to contract any more. A new star soon starts to move through the inter-stellar gas at a relative speed much less than the speed at which the gas and the star move round the galaxy. The star collects some of the gas by gravitational attraction, the slower the relative motion of the star through the gas the more gas collected, and a tunnel is left in the gas behind the star. Most stars move sufficiently quickly through the gas, about 30,000 m.p.h., for only a very little gas to be collected, but a few moving at less than 5,000 m.p.h. collect so much gas that their size is appreciably increased.

If two stars happen to stay together for some time on their journeys round the galaxy, they will sweep out nearly parallel tunnels of inter-stellar gas and the effect of this is to bring the stars closer together. After a time, the two tunnels merge and become one; still later on, the stars start to move around each other, all the time growing in size as they collect more inter-stellar gas and all the time getting closer together. Observations have shown that there are nearly as many double star systems as single stars, and that some multiple stars exist. Castor is a system of six stars, and the Pole Star a system of five.

To complete the general picture, you should know that there is much more material in all the inter-galactic gas than in all the galaxies, and much more material in all the inter-stellar gas than in all the stars. The most important thing in the universe would seem, therefore, to be the inter-galactic gas.

Let us now come back to the Earth and look out into space with a telescope. You can see a vast number of galaxies, all very similar to our own; if you are using a very large telescope you will see about 100 million galaxies all spaced about one million light-years apart. All these galaxies will appear to be moving away from us, the further away the galaxy the faster it is moving away. This does not mean that we are at the centre of the universe, for if you could travel to another galaxy and have a look from there, you would get just the same impression. What is really happening is that the space between the galaxies is stretching all the time in a uniform manner, and this, of course, accounts for the observed effect. If you were to make a telescope twice as large as the biggest one made so far, the furthest galaxies would appear to be receding with the velocity of light. You could never see anything further away than this, because the light would never reach you. However, as everywhere you look things appear to be much the same, it does not really matter that your vision is limited in this respect. On second thoughts, though, this situation appears to be a little peculiar, for if the galaxies are all moving away from each other, some time ago they must all have been at one place; and if we waited long enough they would all be beyond the range of our largest telescopes. The idea that everything started at one place and expanded from there does not fit in with our observed knowledge of the recession speeds, the ages, and the general structure of the galaxies. The idea of the galaxies condensing out of the inter-galactic gas does fit in with the observed facts and this is why the existence of this gas is postulated. It is suggested that new galaxies are forming all the time, so that if we could wait a few million years and have another look into space, we should still see just as many galaxies as we do now. It is also suggested that, rather than consider a beginning and an end to the universe, which does not seem to fit in with the general pattern of continuity observed in the universe as a whole, it would be more reasonable to consider no sudden change but rather that the inter-galactic gas is being continuously created at a rate that exactly equals the amount being used up in the formation of new galaxies. To put it the right way round, inter-galactic gas is being continuously created at a fixed rate and a state of equilibrium exists throughout the whole universe. If this idea seems to conflict with the thought that the conservation of energy theory must in some way apply to any system that you might consider reasonable, it must be pointed out that the old idea of a single creation at one time and place, followed by a gradual running down of the universe as it expanded, involves a gradual loss of energy until there is none left. The idea of continuous creation infers that the total energy in the universe remains the same. This new suggestion is that the universe goes on for ever into the future and went on for ever into the past. Creation, whether sudden or continuous, must be accepted, for the hydrogen to helium nuclear transmutation is using up material which must have come from somewhere.

After this large-scale survey of the general features of the universe, we shall now take a look at some of the details. One detail of great interest is the origin of the solar systems, in particular our own. It was thought that the planets were formed out of the Sun, one theory being that the material was dragged out of the Sun by the attraction of a passing star. We now know that if this had occurred, the planets would lie much closer to the Sun than they in fact do. An alternative theory suggested that the planets were formed when the Sun was young and much larger, that is, in the early stages of condensation out of the inter-stellar gas, but there is no satisfactory explanation of how this could have occurred. Both of these theories break down when we remember that the Sun is composed mainly of hydrogen while the planets consist mainly of iron, calcium, silicon, etc. Incidentally, most bodies in the universe are composed of hydrogen and helium, the Earth being unusual, but by no means unique, in its composition. A new theory is that there was once a star forming a double star system with the Sun and that this star contained a preponderance of heavy elements like iron and calcium. It exploded violently, most of it being thrown into space and a little remaining near the Sun as a cloud of gas from which the planets condensed.

There is a kind of star, called a supernova, that behaves in the right way to fit in with this theory. A very large star uses up its hydrogen more quickly than a normal star, as it has such a large radiating surface, and when all the hydrogen is used up the star begins to collapse. The consequence of this collapse is a raising of the internal temperature and an increase in the rotational speed. Usually, this high rotational speed gradually throws off the outer material of the star, which just gradually runs down. Sometimes, however, very little material is thrown off and the internal temperature becomes so high that helium is converted into heavier elements. This type of conversion uses up energy, which is supplied by a rapid contraction of the star, which in turn causes the rotational speed to increase to such an extent that the whole star explodes. The whole of the final stage lasts about one minute and just before the explosion the star is so dense that a cubic inch weighs about a thousand million tons. Such explosions are occasionally observed in the universe, and they produce as much light as all the stars in one galaxy put together.

Ordinary stars like the Sun are also using up their hydrogen, though at a much slower rate, and they also shrink and get hotter when all the hydrogen is used up. In the later stages of hydrogen to helium nuclear transmutation when there is only a little hydrogen left, the star expands to some extent and gets hotter on the outside. As far as the Earth is concerned, we shall all be roasted in about ten thousand million years. The hydrogen in the Sun will last for about fifty thousand million years. So much for the end of the Earth, but what about the end of the galaxy? Unfortunately, we can never expect to see an old galaxy, as the galaxies are receding at the speed of light when they are still quite young. We know that a galaxy will gradually become more massive as it collects more inter-stellar gas, but we do not know what happens to an extremely massive body of this kind.

Another detail of general interest is the probability of life elsewhere than on the Earth. It is possible to make a guess at the answer to this question. If we assume that solar systems are formed when supernovae explode, and as we know how often supernovae explosions occur, we can give an approximate figure for the number of solar systems in a galaxy. The same reasoning may be applied to any other of the current theories of how planetary systems are formed, and although we may arrive at a slightly different numerical answer, we are not likely to be out by more than a factor of ten or so. Working on the supernova explosion theory, we find that the probability of a planet being formed with a suitable atmosphere to support life is such that there must be at least 100,000 such planets in one galaxy and probably more like 1,000,000. Allowing for different theories of the formation of planets, let us say that one galaxy like our own will contain between 10,000 and 10,000,000 planets with atmospheres capable of supporting life. From the biological point of view, life is almost certain to exist in some form on every one of these planets, and the chances of its developing in much the same way as it has on the Earth seem to be fairly high. It does look, therefore, as if we are not unique creatures, but that we are something of a rarity.

You will have noticed that we are now in the realms of conjecture. We should go no further along these lines until more observational or mathematical evidence is available. I have no doubt, however, that these and many other open questions will receive satisfactory answers in the next few years, and also that many of the ideas that we now have will be extended to give us a picture of the universe even more wonderful than that we see today.

## YOUR NAME AND NUMBER

The numbers 0, 1, 2, . . . 9, that we use today in mathematics were first used in India; they did not reach Western Europe until the Fourteenth Century. Before that time the Romans had used the figures I, II, III, IIII (not IV), V, and so on, but the Greeks and other civilized peoples had earlier used the letters of their alphabets in a kind of code. Thus the Greeks used $\alpha = 1$, $\beta = 2$, $\gamma = 3$, . . ., $\iota = 10$, $\kappa = 20$, $\lambda = 30$, and so on. To show when the letters were being used as numbers a bar was written over them.

This system of the Greeks was not only very inconvenient but it also gave rise to the curious science of Gematria. If a Greek wrote his name, he also wrote a number, so everyone had a personal number corresponding to his name; every word also had its number. The principle of Gematria was that names or words with equal numbers were equivalent. If therefore you quarrelled with a man whose number was, for example, 73, all you had to do was to find all the discreditable words whose number was also 73. If you could show that 73 was the number of a word meaning "liar" or "the Devil" your case was proved! Your opponent would of course be doing similar research on *your* name and number.

# How a London Bus Works

D. ROSS INGLIS

HAVE you ever wondered how the fuel which is put into the tank eventually turns the rear wheels of a bus? Have you ever tried to imagine what goes on under the bonnet and under the floor-boards?

If you read the following, you will discover this, because we are going to trace the mechanics of the bus right through, and learn how it is driven.

Before we actually begin, though, a word must be mentioned about the vehicle as a whole. We are dealing with the newest and most common type of London bus, and these are powered by oil engines, so the details of the motive-power unit will not apply to your father's car, because in all probability he owns a petrol-engined vehicle. Another point to bear in mind is that the buses are fitted with a fluid flywheel and a pre-selective gearbox, so there is no clutch, and the pedal which takes the place of it on the left of the driver's floor-board is the change-speed pedal.

Now some other details. The oil engine develops about 125 brake horse-power. The b.h.p. is the amount of power available at the output of the engine; the effort, if you like, which is required to stop the engine when it is developing full power, in this case when the crankshaft is turning at 1800 revolutions per minute.

And do you know what a horse-power is? It is the unit which engineers use when speaking about power, and you will understand what it is if you realize that it is *a rate of doing work.* If a man runs up a steep flight of stairs as fast as he can he is working at about 1 horsepower. The engine of a London bus develops 125 h.p. at the output shaft, that is, 125 b.h.p.

There is one thing you must realize, though. When we talk about an Austin 7, we do not mean that the car develops 7 b.h.p. This figure is a number which, until quite recently, was calculated from the engine dimensions, for the purpose of taxation. It is called the "R.A.C. rating", but from an engineering point of view, it is most deceiving and tells nothing of the actual capacity of the car. (If you are interested, the figure is calculated by the formula: $\frac{nd^2}{2{\cdot}5}$, where $n$ = the number of cylinders, and $d$ = the diameter of each cylinder in inches.) If you want a comparison between a London bus and a private car, we can say that the bus has a R.A.C. rating of about 53 or 54.

For the sake of this explanation, we can divide the chassis (that is, the bus without the body on it) into 3 parts:

(1) The engine, which converts the energy in the fuel into mechanical power;
(2) The transmission, which, with the gearbox, transmits the power developed by the engine to the rear wheels;
(3) The controls, by which the driver can manage his vehicle safely and easily.

The engine fuel is a heavy oil, cheaper than petrol or aviation spirit because it is not so refined, and therefore it has a higher "flash point", which means that it will not catch fire so easily. The fuel is taken from the fuel tank (passed through a filter) by a fuel-lift pump, and is fed into the fuel-injection pump. This (the most complicated part of an oil engine) is responsible for injecting the right amount of fuel into the right cylinder at precisely the right moment. The fuel is pumped into the cylinder as a spray through the injector, at a pressure of 150 atmospheres, which is equal to 1 ton per square inch. This, you will agree, is an enormous pressure, and the fuel enters the cylinder in an "atomized" state, and so it mixes with the compressed air very thoroughly. A diagram of the engine faces page 199.

The fuel oil is injected into the cylinder when the piston is approaching the top of its stroke, which is called the "top dead centre". At this point the piston has compressed the air in the cylinder into a volume one-sixteenth of the original volume when the piston was at its "bottom dead centre".

Perhaps you will often have put your finger over the hole of your bicycle pump, and discovered that on pumping your finger gets very hot. This is due to the quick compression of the air. Similarly, then, the air compressed in the cylinder when the fuel is injected into it is also very hot; so hot, in fact, that it makes the fuel burn almost as soon as it enters the cylinder. This burning produces a rapid expansion of gases, and so it forces the piston down again, with a great pressure on the top of the piston known as the piston crown. The piston is linked to the connecting-rod by means of a gudgeon pin, and the connecting-rod is linked to the crank of the crankshaft; so, as the pistons come down with this force, two at a time, the crankshaft is turned.

The engine, like most internal combustion engines, is a four-cycle power unit. This means that when the piston has moved up and down four times (only once on the way down has it produced useful work) it starts the same thing over again.

We discovered how the piston was given its power stroke. Now, when it reaches its "bottom dead centre", the exhaust valve in the cylinder-head opens. As the piston moves up again (the other pistons doing the work turn the crankshaft) it pushes the burnt gases out into exhaust, via a silencer and the exhaust pipe. When it reaches the "top dead centre" again, the inlet valve (also in the cylinder-head) opens, and as the piston goes down it draws air into the cylinder. At "bottom dead centre" the inlet valve closes (the exhaust is still closed), and as the piston moves up it compresses the air; at "top dead centre" again, with the air compressed and so very hot, the fuel enters and the cycle begins again.

Imagine at what speed all this goes on. We have described the cycle for one piston only, and there are six in the engine, so when the crankshaft is turning at 1800 r.p.m. (the maximum speed), each of the six pistons must be moving up and down 30 times per second.

That is how the fuel is converted into mechanical energy. It is burnt, the gases force the piston down, this turns the crankshaft round and round; thus at a speed of 1800 r.p.m. the horse-power is 125 at the output shaft.

Let us now discuss very simply the main parts of the engine as a unit. The cylinder block is one large casting with six bores in it which form the six cylinders. Bolted to the top of the cylinder block are two cylinder heads or covers, each covering three cylinders. In these heads, over each cylinder, is the injector (through which the fuel is injected into the cylinder), the inlet and exhaust valves. The block and heads are castings of iron, with passages inside all round them for the cooling water to flow through. The water is pumped and kept flowing; it passes through many tubes in the radiator so that the air passing through it when the vehicle is running will cool the water before it is returned to the water-jacket passages. Bolted to the bottom of the cylinder block is the crankcase, where the crankshaft turns in seven main bearings, and bolted to the bottom of the crankcase is the sump, which forms the floor of the engine, where all the lubricating oil for the engine is stored. There is an oil filter in the sump, and a pump on the front of the engine which ensures that the important parts are lubricated under pressure.

The valve-operating gear is worked by pushrods from the camshaft, and by the rockers on the cylinder head. Because the camshaft is geared to the crankshaft, and also to the drive which operates the fuel-injection pump, the engine can quite easily be timed as accurately as required. It is most important, as you will have realized, that the petrol is injected, and the valves are opened and closed, at precisely the correct split second, because the slightest alteration in the timing would reduce the efficiency very much or even stop the engine. There are what are known as "timing marks", therefore, on various components of the engine which must be aligned when the engine is dismantled and reassembled.

The fuel-injection pump is fitted on the side of the engine, and six pipes lead from it to the six injectors, one for each cylinder.

Two points ought to be noticed about oil engines. One is that you will often hear them called "Diesel engines". This term is not strictly accurate although they are a type of Diesel engine. A man called Diesel first devised the principle on which these engines run, but improvements in design have changed the original idea considerably. The other point is that there are two main types of oil engine, the direct-injection and the indirect-injection. The indirect-injection was the first Diesel design, in which the fuel is not injected directly into the cylinder but into what is known as a combustion chamber. This is a small spherical recess in the cylinder head with a passage, called the "venturi", leading into the cylinder. The expansion of the gases produced by the burning oil takes place in the chamber and the pressure enters the cylinder through the "venturi". The later design, which we are discussing here, is the direct-injection, in which the fuel is injected directly into a recess formed in the crown of the piston.

So the Diesel engine has indirect injection, with the combustion chamber in the cylinder head; the newest London buses are fitted with direct-injection oil engines, in which the combustion chamber has been superseded by a combustion recess in the piston crown.

With the power at the output shaft of the engine, we must see how it reaches the rear wheels. Normally the clutch is the link between the engine and the transmission, but modern London buses have a fluid flywheel instead.

First let us deal with the operation and function of a clutch. This is a device for connecting or disconnecting two revolving parts at will so that a drive can be taken from one part (the engine) and passed either partially or wholly to another part (the transmission). It consists, as you probably know, of two plates facing one another (in some cases more than two) and each is lined with a friction material. When the clutch is engaged the two plates are held forcibly together so that there is no slip between them and the driving plate turns the driven one. When you start, or when you change gear, you want to ensure that at first there is much slip between them so that the power of the engine is not all taken up suddenly. This slip is achieved merely by letting the plates come together slowly and with little pressure, so that at first the driven plate only turns, say, ten times for every hundred times the driving plate turns. As you bring them together with more pressure, the slip becomes less, until you have a "solid transmission". That is how a car is able to move forward slowly, and why, if you let the clutch pedal out too quickly, either you go off with a jerk or else you "stall" the engine and stop.

But in a bus you have no clutch, and a fluid flywheel takes its place. This, like the clutch, is in two parts, but these are two wheels with pockets and fins on their surfaces, which are set at a very small distance apart. The driving half is bolted to the crankshaft, and the driven half is connected to the gearbox; there is no mechanical connection between the two halves, however. The whole is encased in an oil-tight bell-housing which is nearly full of oil. When the engine starts and the driving half turns with the crankshaft, the oil in the housing is forced outwards. This force is called "centrifugal force", and is the same as the force that keeps the water in a bucket when you swing a halffull one over your head on a piece of rope. The faster you swing it, the less chance there is of the water falling out to wet you, so the faster the driving half of the wheel turns, the greater is the force of the oil staying in the pockets, both of the driven and of the driving halves. Now there comes a point where the oil cannot help taking the driven half round with it, and the faster the driving half turns the less slip there is, until eventually the oil forms a "solid" transmission between the two halves. The principle can be likened to that of an old water mill. The miller adjusts his water-wheel so that the fins are below the surface of the stream; the faster the stream flows (the faster the driving half turns) the faster the mill turns (the faster the driven half turns).

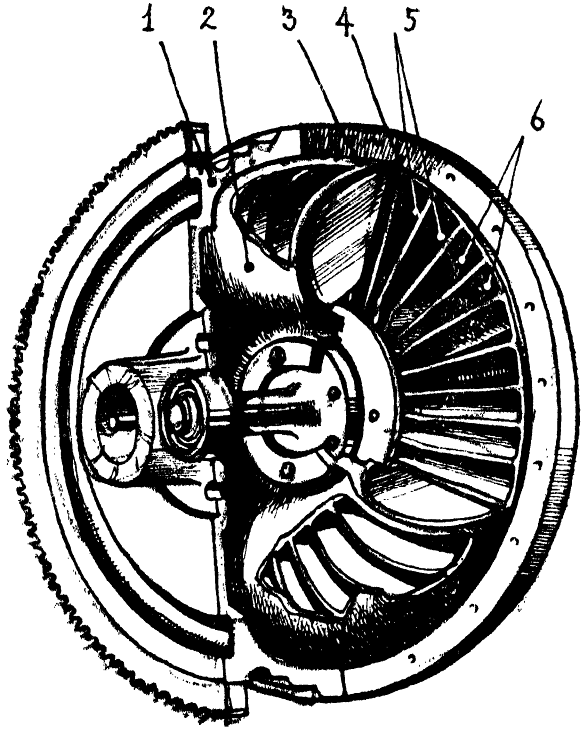


Fig. 1. A fluid flywheel. (1) Outer bell-housing; (2) inner half of flywheel; (3) inside driving half; (4) inside driven half; (5) fins; (6) pockets.

The driven half is connected to the gearbox by means of a "cardan shaft" (or propeller shaft); this is a hollow tube about three inches in diameter.

The gearbox is very, very complicated; it is known as a pre-selective epicyclic gearbox. It must be sufficient to say that it has four forward speeds and one reverse, and that it is operated by air pressure. The effect is exactly the same as the usual "crash" or "synchromesh" gearboxes, but the operation and working are very different, and so complicated that many garages cannot service them properly.

The function of a gearbox is to allow the vehicle to be moved gradually and to use the power of the engine in stages, as the vehicle moves off and gathers momentum. You might wonder why the engine alone could not be controlled so that the bus could move off slowly and then gather speed as the accelerator is depressed. If the power of the engine were not geared down at first, you would have to start with the engine running extremely slowly, and with the engine running slowly you would not be developing enough power to move the vehicle at all. The faster you run the engine the more power you have; if your bus is full you need a lot of power to pull away.

Briefly, this is what a gearbox does. When bottom gear is engaged, the number of times the output shaft of the gearbox turns is, perhaps, 1 for every 6 turns of the input shaft. In other words the power is geared down. But where, you might ask, does the power go? If there is 10 h.p. going into the gearbox when the input shaft is turning at 600 r.p.m., and if the output shaft is only turning at 60 r.p.m., does it mean that the power at the output shaft is only 1 h.p., by proportion? No, it does not. You lose speed but gain power—which is exactly what you want when starting off.

This can easily be explained. Suppose you place the middle of a six-foot plank on a block of wood; put a weight of 10 lb. on one end. Now, if you push on the other end with a force of 10 lb. you will be able to raise the weight exactly the same distance as you move your hand. When you have tried that, put a weight of 100 lb. on the end, and move the block of wood right up close to the weighted end. If you push your end down, you will find that only a small push, much less than 100 lb., is required to move the weight up. But what else have you noticed? You have raised a weight of 100 lb. using perhaps only 15 lb. of your own effort, but you have moved your hand perhaps 2 feet and the 100 lb. has only moved 6 inches.

In other words, you geared down your energy so that you could move a heavy weight with little effort, but you have had to move your effort proportionally further than the load was moved.

Back to the gearbox. The input shaft turns 600 times and the output only 60 times, but the engine is turning less quickly, that is, developing less power, than would be required if no gearing were used to start off.

When you engage 2nd gear, the number of times the output shaft turns in proportion to the input is greater than in bottom gear; in 3rd it is greater still, and in 4th, or top, there is no reduction at all; the transmission is direct. You can afford to use higher gears, and eventually top, as the vehicle is moving, because it takes less effort to keep the bus running than it does to get it going. So when you have changed up all the gears and engaged top (which you remember is direct) you can afford to use all the engine power, ungeared, to keep the vehicle moving.

When you come to a hill the bus is required to do extra work to climb it, so more power is required. All you have to do, therefore, is to change down; this will give you more power but less speed—again, exactly what you want. In traffic you change down also, so that the shaft going into the gearbox is turning a greater number of times than the one going out of it, thus giving you a lower speed.

From the gearbox, then, the output shaft consists of another cardan shaft going to the rear axle. The cardan shaft goes into some more gearing in the middle of the rear axle called the "differential". (Sometimes the differential is offset on one side of the axle so that there is not a "hump" on the floor inside the bus; you can sometimes see the hump on the floor near the seat set lengthwise at the back of the bus.) By means of the gearing, known as the worm shaft and worm wheel, the drive is distributed by two half-shafts to either road wheel.

But the differential has two very important duties, other than distributing the drive to the rear wheels. Firstly, it is another and constant reduction gear. If the transmission were not geared down at this point, it would mean that when the engine was running at full revolutions, 1800 r.p.m., and top gear (direct, you remember) was engaged, the road wheels would be turning at 1800 r.p.m. also. This, of course, would be far too fast. So the differential gears the drive down to either 6, 5, or 4 to 1. Supposing it is 5 to 1, it would mean that the road wheels would turn once for every 5 turns of the cardan shaft linking the gearbox and the rear axle. In bottom gear, where there is a reduction of about 6 to 1 in the gearbox, the road wheels would only turn once for every 30 revolutions of the engine—

providing there were no slip in the fluid flywheel, which is unlikely in bottom gear. This total reduction of 30 to 1 is calculated by multiplying the differential reduction by the gearbox reduction ($5 \times 6 = 30$).

The other very important function of the differential is that it controls the turning of each rear wheel when the bus is turning a corner. When the bus goes round a corner, the front wheels are turned by the driver at the steering wheel, but the rear wheels are not. Now this is very important.

Supposing the bus is turning a complete circle. In completing the circle the outside wheels of the bus will have to cover a greater distance than the inside wheels. We can see how this happens if we place a halfpenny centrally on a penny, and we see that the edges of the coins are parallel but that the penny has a longer circumference. Imagine the bus going round in this circle, with the inner wheels on the edge of the halfpenny and the outer wheels on the edge of the penny, and you will then realize how the outer wheels have a greater distance to cover.

The front wheels are steered by the driver, but because they are not driven, each can decide for itself, as it were, how many times it is going to turn. The rear wheels, however, are being driven, so without the differential they would have to turn the same number of times always, which would mean that when the bus was turning a corner, the inner wheels would have to slip so that they could cover a shorter distance in the same time as the outer wheels. This would produce, as you can well imagine, a very great tyre wear. But there are what are known as "bevel gears" on a "spider" inside the worm wheel of the differential, which rotate and take up the extra turns of either wheel (depending on the direction the bus is making the turn) as soon as it offers a resistance to turn, and allows it, as the front wheels do, to turn as often as it pleases.

And so, thanks to the expanding gas caused by the burning of the fuel oil in the cylinder, the rear wheels of a bus are turned.

Going back briefly, we have found that the pistons move down to turn the crankshaft by means of the connecting-rod; the driving half of the fluid flywheel (bolted to the crankshaft) eventually turns the other half because the oil which is being flung into the pockets and fins of either half gradually brings the driven half with it and so produces a "solid" transmission; the first cardan shaft takes the power to the gearbox, where it is converted, if need be, into a lower speed with a greater power; the second cardan shaft takes the drive to the differential, which gears it down again, distributes the drive to either wheel, allowing each to turn the same number of times when the vehicle is moving along a straight road, and allowing one wheel to turn more often than the other if necessary.

So the energy in the fuel oil is converted into mechanical power at the wheels.

How is this 125-h.p. engine controlled? There are three pedals in the driver's cab. On the right is the accelerator pedal which the driver moves down to increase the speed. The pedal is directly linked with the fuel-injection pump and the further he depresses it the greater the quantity of fuel he injects into the cylinder, causing greater pressure when it burns; this forces the pistons down more quickly and so turns the crankshaft at a greater speed. To stop the engine, the driver need only reach down and pull the accelerator pedal up slightly, thus shutting off the supply of fuel.

On the left of the accelerator pedal is the foot brake. Most of the London buses have air-operated brakes; that is, when the driver depresses his pedal he allows air into each of the wheel brake cylinders. These are little cylinders mounted on the inside of the wheel (the part which does not go round, of course) and the stem of the piston inside them is linked to a cam which expands the brake shoes within the revolving brake drums, and so applies the brake. The shoes are lined with a friction material (like the lining of a clutch) and this rubs against the brake drum with a force behind it proportional to the force the driver applies on his pedal. The effect of this braking principle is the same as when you put your hand in a jam jar and turn the jar round your hand; supposing you clench your fist so that much of the outside of your hand is rubbing on the inside of the jar, you will find that it is more difficult for you to turn the jar; if you clench your fist a little more, so that the pressure between your fist and the jar is greater still, you will probably find that you cannot turn the jam jar at all.

Practically all road vehicles are fitted with this expanding brake-shoe type of brake, though many are assisted by oil or vacuum instead of compressed air. The air which is used for the brake operation is compressed by a two-cylinder compressor and stored under pressure in an air reservoir mounted on the side of the chassis. It is from this reservoir too that the air for the gearbox operation and automatic lubricator is taken.

The hand brake is the lever on the right of the driver; this operates the brake cams of the rear wheels only, and is connected to them by a direct mechanical linkage. (By Law, any road vehicle must have an independent and alternative means of braking.)

The pedal on the left of the floor-board is the change-speed pedal, and the use of this can best be explained if we describe how the vehicle is driven.

With the engine running slowly or "idling", there would be no slip in the fluid flywheel when the gearbox was in "neutral" (that is, when no gear is engaged), so the cardan shaft to the gearbox would be turning but not the one from the gearbox to the differential.

To drive away, you would see that your hand brake is fully on and you would pre-select bottom gear by moving the handle on the little box which is bolted on the left under the steering wheel. By doing that you have "pre-selected" (that is, selected before actual engagement) bottom gear. As soon as you depress and release the change-speed pedal (and this must be done quickly), you will have engaged first gear. But the vehicle will still not have moved. With the hand brake on and the gear engaged—so long as the engine is only "idling"—all the slip will be taken in the fluid flywheel. Not until you release the hand brake and accelerate slightly will the bus move off. As it is moving, you will pre-select 2nd gear on the selector, and when the vehicle is moving along comfortable you would only need to release the accelerator momentarily, depress and release the change-speed pedal again, and the bus would be in 2nd gear, ready for you to accelerate a little more. You do the same thing to engage 3rd and top gears, and when you are driving along in top, you would pre-select 3rd gear again by moving the selector handle, so that you would only need to depress and release the change-speed pedal to be in the lower gear.

If you look into the driver's cab, you will see a little knob on the left of the selector box. The driver has merely to pull this knob out and push the handle along a little further when he wants to pre-select reverse gear; the operation to engage it is exactly the same as for the other gears.

A few words about the future of *our* bus. If you have not seen one already, because there are only a few about, you will very soon see a bus with the engine under the floor, slung on the side of the chassis and under the frame.

This new idea has three very important advantages. First, it provides more room for passengers because seats can be arranged right up in front of the lower deck next to the driver. Secondly, the noise from the engine cannot be heard nearly as much. Thirdly, it makes the engine very much easier to get at for servicing. In fact you could take the engine out in less than twenty minutes whereas to take the engine out when it is in front might take as long as three hours.

## GENIUS ON GENIUS

"No one ever left knowledge in a state so different from that in which he [Newton] found it"—Einstein.

"I have been but as a child playing on the sea-shore; now finding some prettier pebble or more beautiful shell than my companions, while the unbounded ocean of truth lay undiscovered before me"—Newton.

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